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ROYAL AERONAUTICAL SOCIETY 1866

Journal

of

THE ROYAL AERONAUTICAL SOCIETY

OCTOBER 1956

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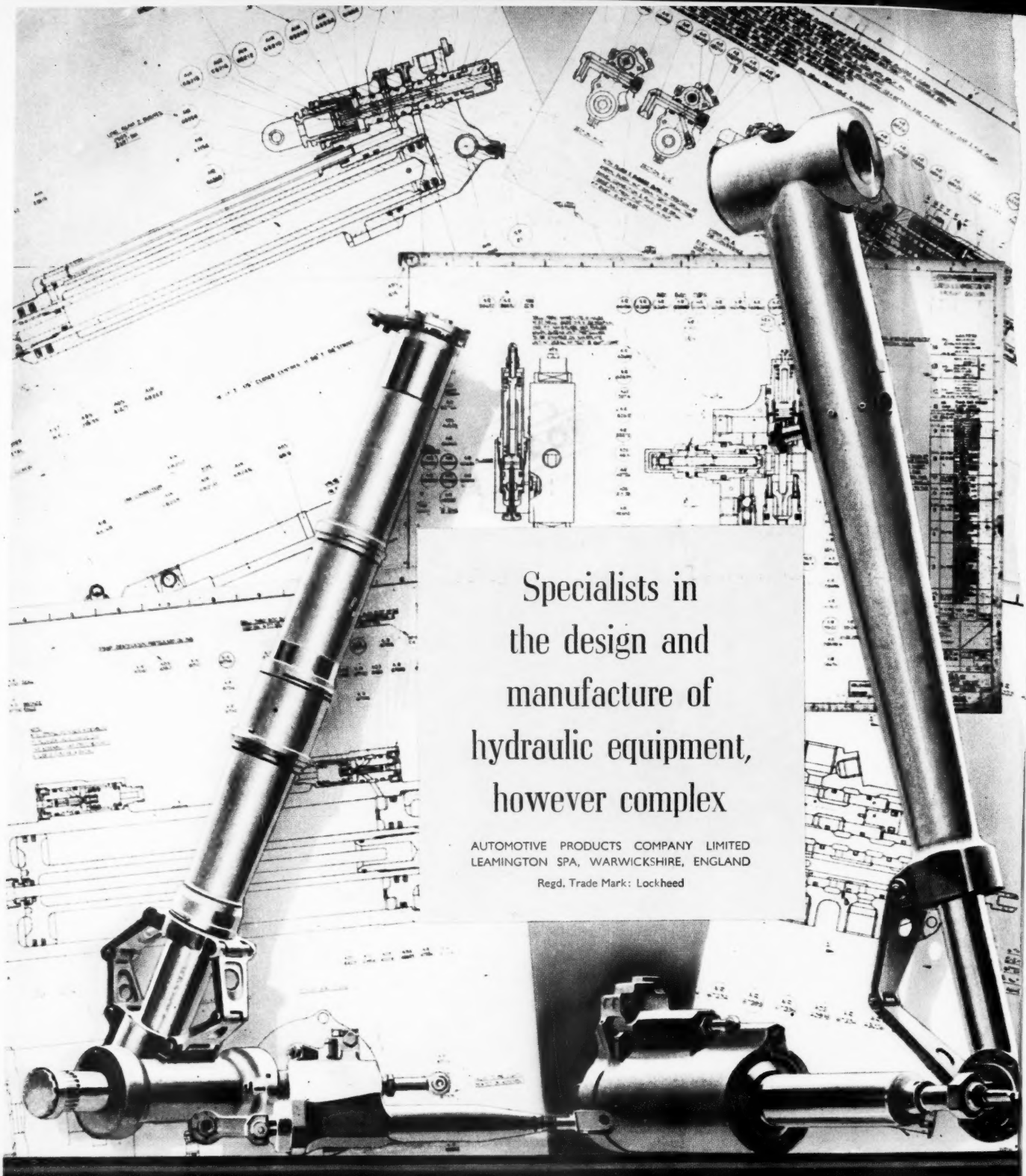

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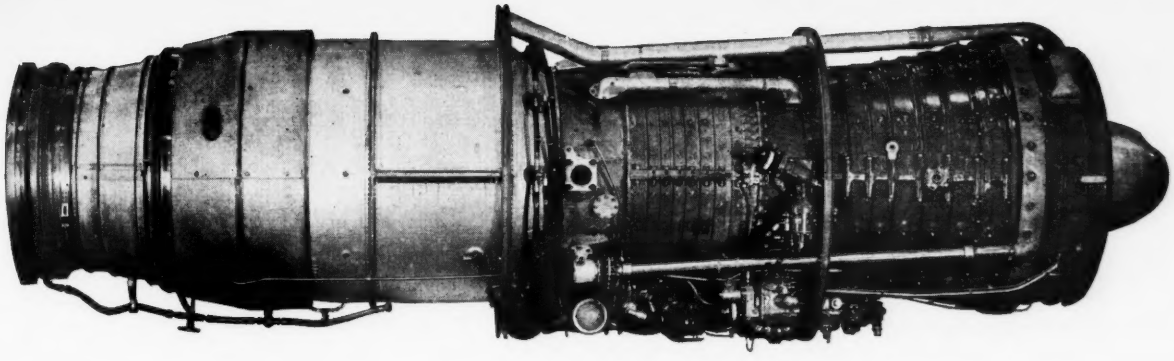

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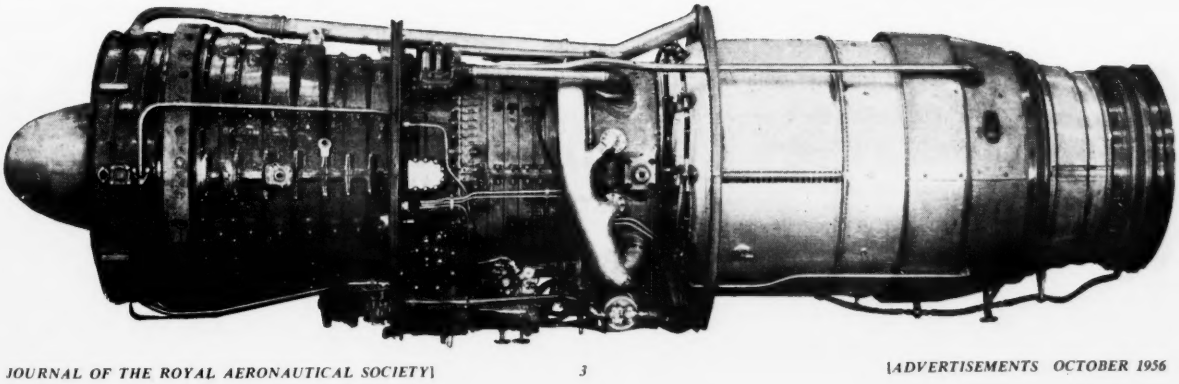

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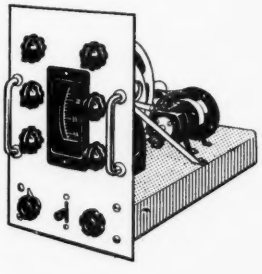
Designed to return to a balanced condition and therefore independent of supply voltage, etc., the mechanism indicates the strain on the periphery of a drum, providing a long scale with economy in space. The drum shaft can be coupled directly to a digitising disc, giving results in a form suitable for use with digital computors.



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data sheets

on

fuels and lubricants

A new issue of Fuels and Lubricants Data Sheets has been prepared and will shortly be sent to all holders of the original issue. The new issue includes revisions to the existing sheets on fuels and a new group of sheets on lubricating oils. Concise summaries of current specification requirements (both U.K. and U.S.A.) are given, while many of the sheets collect together data that are often difficult to obtain elsewhere.

The issue has been prepared by the Royal Aeronautical Society in conjunction with the Institute of Petroleum.

THE ROYAL AERONAUTICAL SOCIETY
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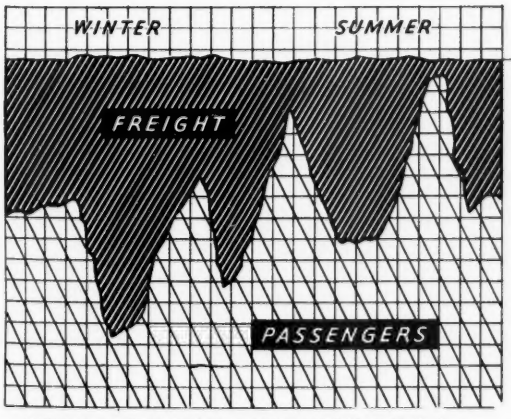
A winter night . . . passenger traffic at its lowest ebb . . . but full payload will be achieved with the Vickers Vanguard, at any season of the year, and at any time of day. In off-seasons, when passenger bookings diminish to a trickle, freight can be increased up to a maximum of 21,000 lb. The balance of freight and passengers can be continuously adjusted, without structural conversion, to meet any density of traffic, and still give profitable operation.



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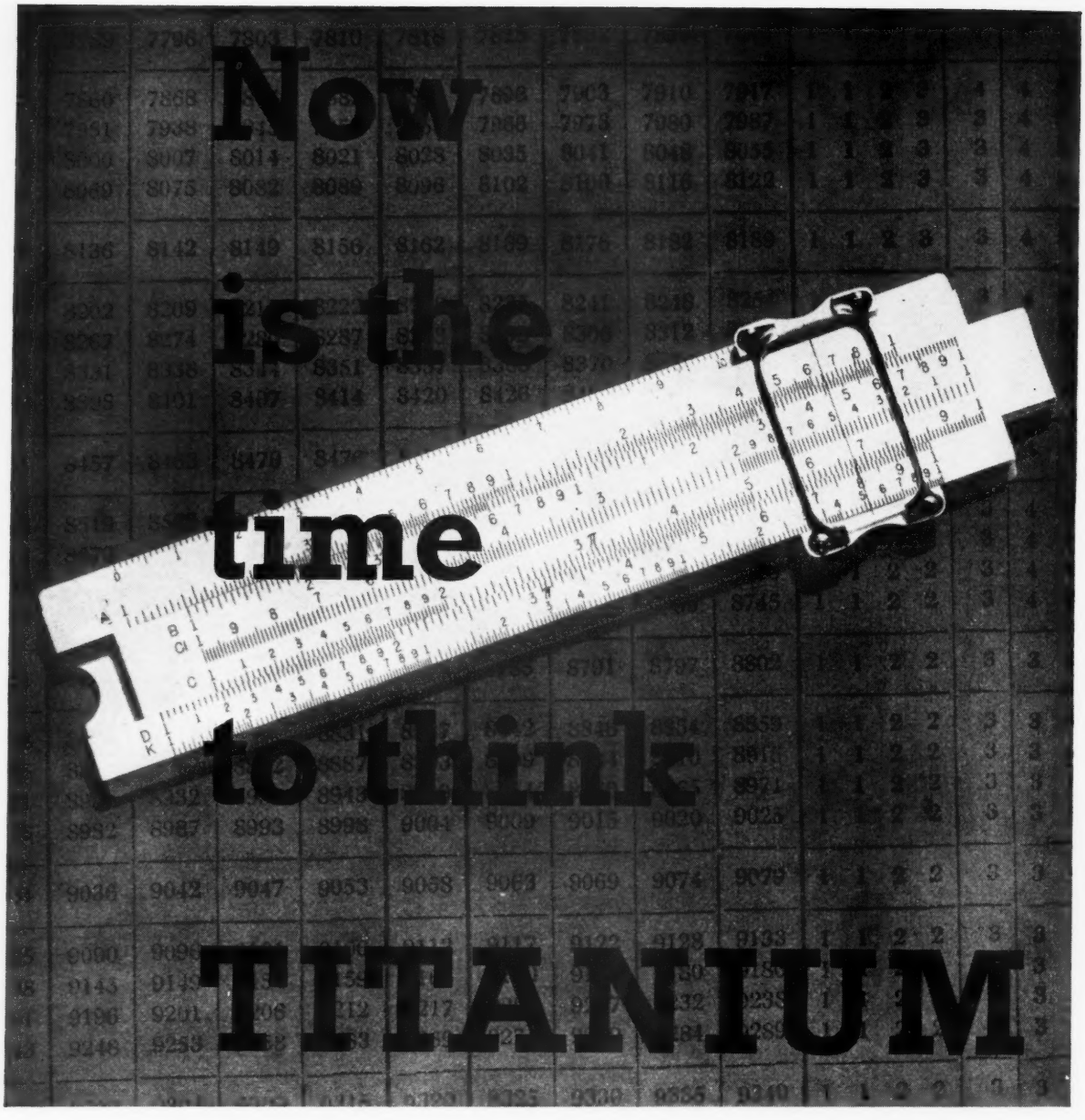

TALKING POINTS NO. 2 . . . Titanium and the "Temperature Barrier"

In spite of the high melting point of titanium (about 1700°C), the strength characteristics of the commercially pure metal are lower than might be expected at temperatures above 300°C.

Experience has shown, however, that strength at temperature can be much improved by alloying, and I.C.I. is devoting considerable attention to the alloying behaviour of titanium and the development of new alloys. Promising alloys (such as I.C.I. Titanium 317 and 371) are tested for long-term strength properties in the I.C.I. Creep Test Research Station, where over sixty special testing machines are in continuous action.

Titanium alloys having good strength at temperatures up to 450°C have already been developed. Further researches now in progress should soon raise the "temperature barrier" still higher.

IMPERIAL CHEMICAL INDUSTRIES LIMITED, LONDON, S.W.1

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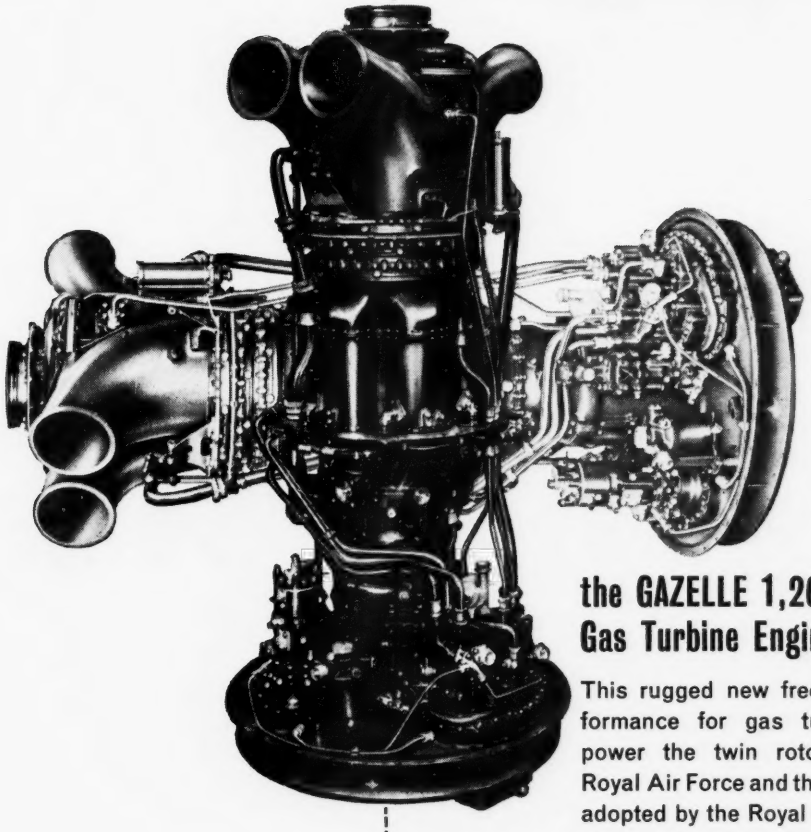
Selected by the Royal Navy and the Royal Air Force



the GAZELLE 1,260-2,000 s.h.p. Gas Turbine Engine

This rugged new free-turbine engine of notable performance for gas turbine-powered helicopters will power the twin rotor Bristol 192, adopted by the Royal Air Force and the Westland "Wessex" helicopter, adopted by the Royal Navy.

The engine embodies the safe, simple Napier automatic control system.

For ease of installation it can be mounted in any position between the vertical and horizontal.

Helicopters demand tough, reliable engines—the GAZELLE is designed for strenuous duty, long life between overhauls, while its outstanding simplicity means easy maintenance and economical operation.

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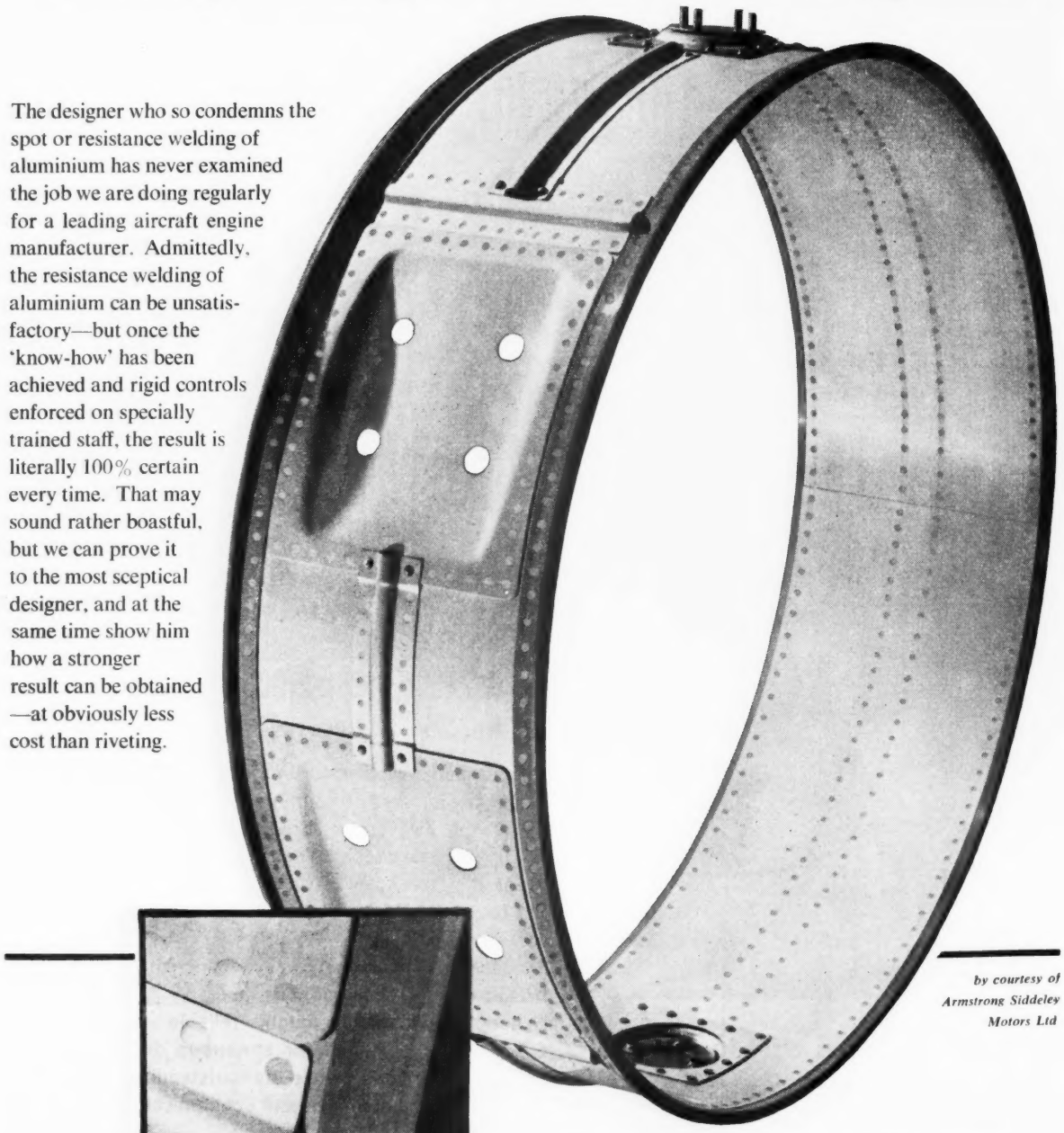
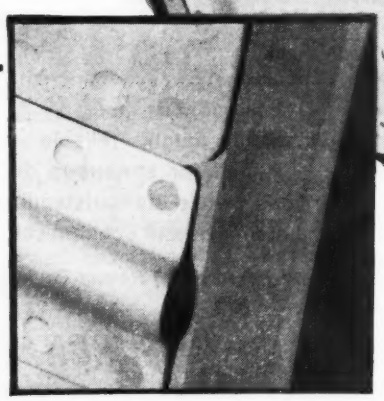
The designer who so condemns the spot or resistance welding of aluminium has never examined the job we are doing regularly for a leading aircraft engine manufacturer. Admittedly, the resistance welding of aluminium can be unsatisfactory—but once the 'know-how' has been achieved and rigid controls enforced on specially trained staff, the result is literally 100% certain every time. That may sound rather boastful, but we can prove it to the most sceptical designer, and at the same time show him how a stronger result can be obtained —at obviously less cost than riveting.



by courtesy of Armstrong Siddeley Motors Ltd



Detail on left shows the variety of metals successfully welded in the above unit; there being a non-heat treatable light alloy, two components of different heat treatable light alloys, all welded to centri-spun light alloy casting.

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Middleton gets metals together

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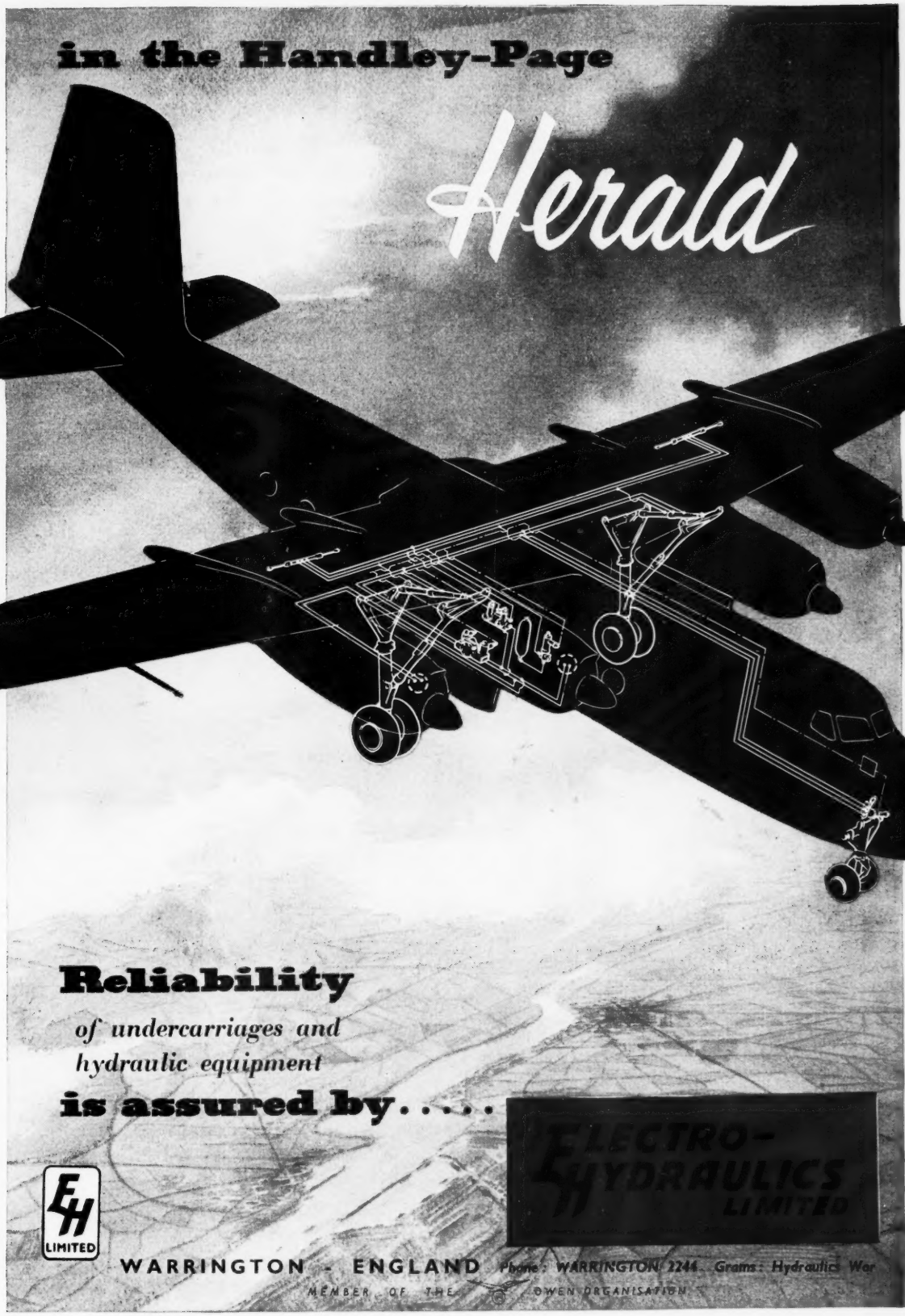
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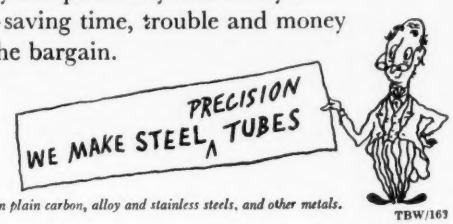

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* Production costs are lower
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Redux is simple to use, especially if specified at the design stage, and our Technical Service Dept. can be called upon for every possible assistance. In the meantime, there is a wealth of literature on the subject, much of it of absorbing interest to the designer and production engineer. May we send you some examples?

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'Redux' is the registered trade name of the adhesive used in the 'Redux' (patented) bonding process.

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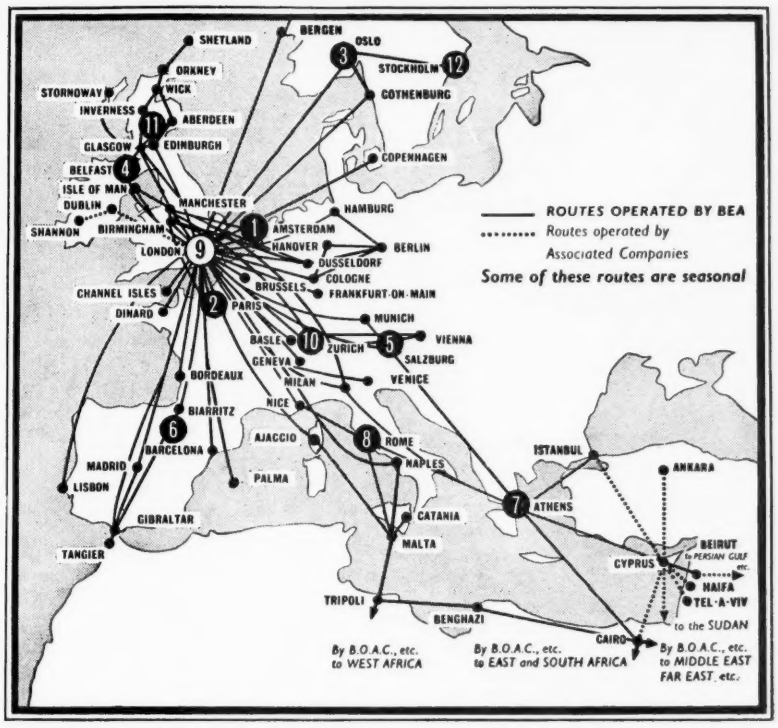

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learning fast...

The rapidity of development during recent years of the Plastics Industry can almost be measured by comparing the number of plastics items used regularly by aircraft constructors to-day and, say, twenty years ago. Plastics, still young, has had to learn the technical requirements of its end users, amongst whom the technicians of the aircraft industry have proved by no means the least exacting. By precept, the Plastics Industry has pledged its service in the search for new or improved materials; a search in which the chemists and engineers of B.I.P. continue to contribute their inventiveness and unstinted energy.

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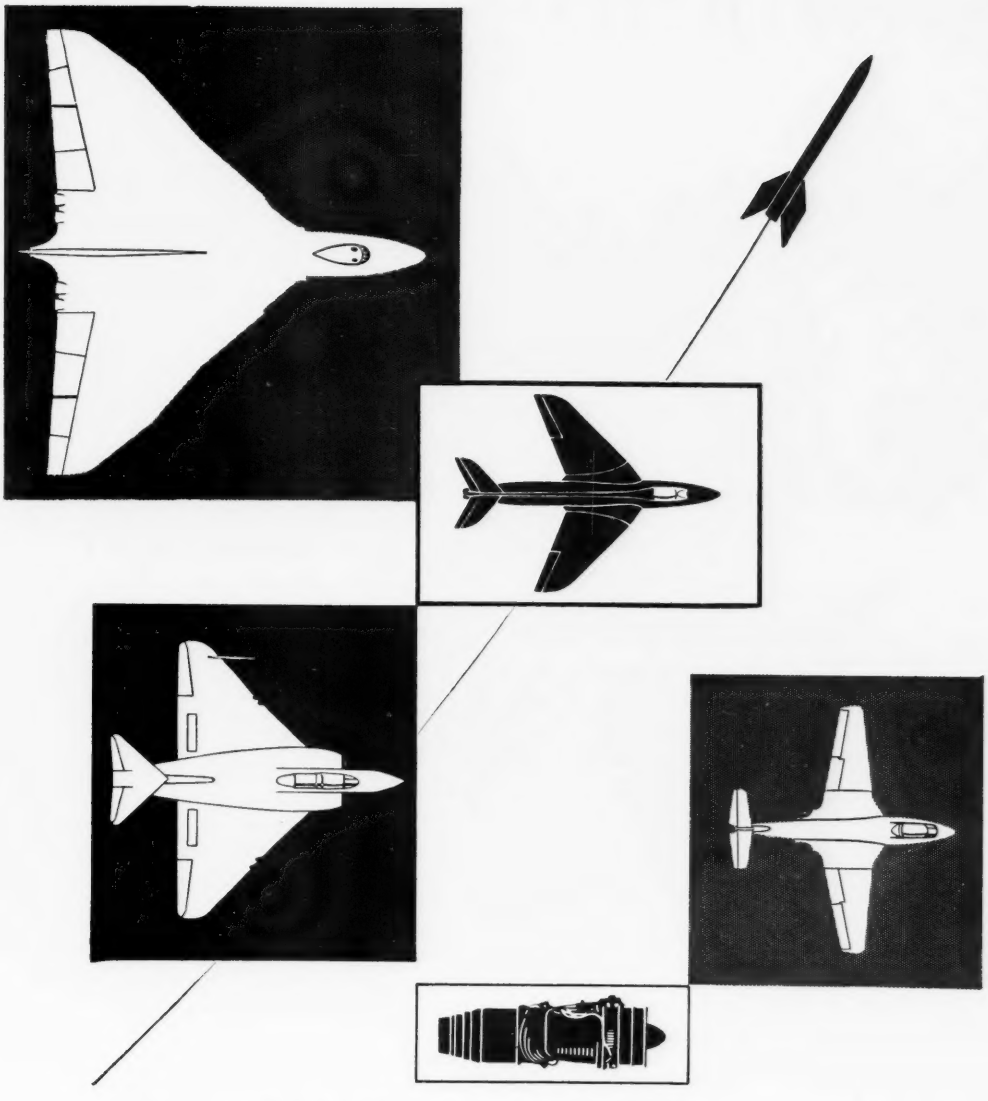

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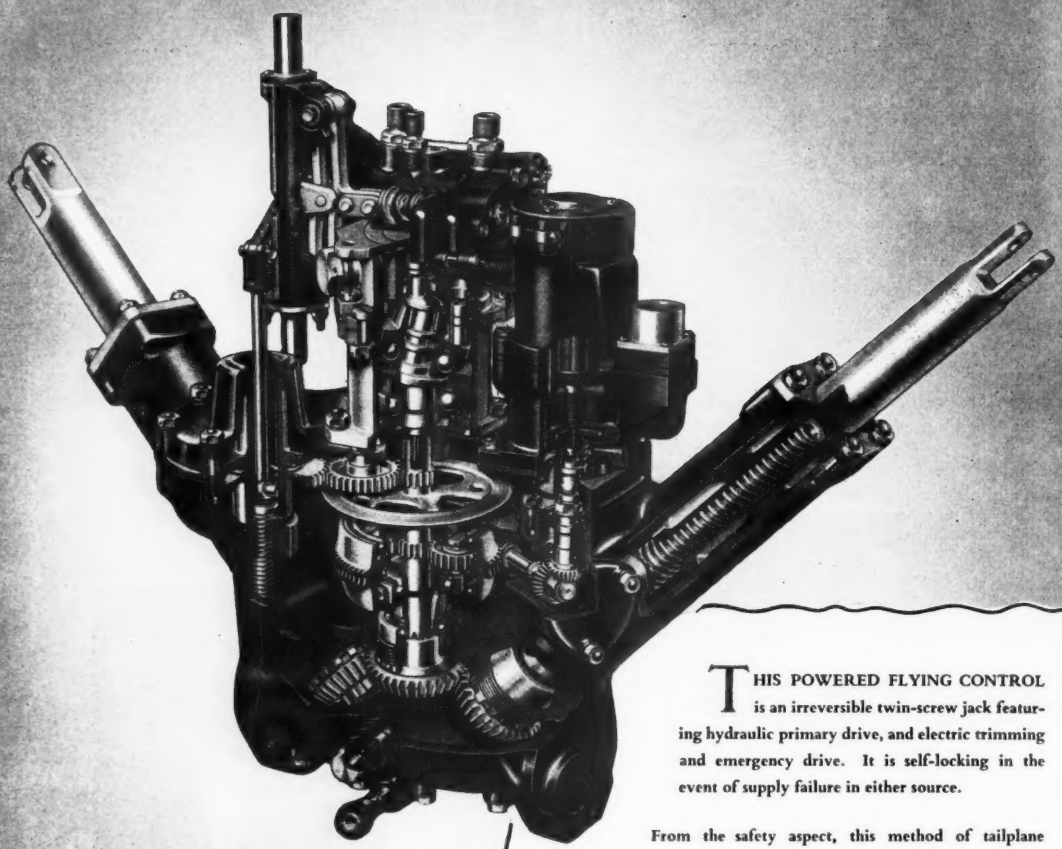
POWERED FLYING CONTROLS



THIS POWERED FLYING CONTROL is an irreversible twin-screw jack featuring hydraulic primary drive, and electric trimming and emergency drive. It is self-locking in the event of supply failure in either source.

From the safety aspect, this method of tailplane operation from separate sources is eminently suitable for a single-engined aeroplane where duplication of hydraulic supply is difficult to arrange.

In its present installation the unit actuates the moving tailplane hydraulically, coincident with mechanical elevator operation in a set angular displacement ratio. The electric drive is used for trimming, and being independent of the mechanical linkage, permits longitudinal control by the elevator in the event of hydraulic failure.

The unit is one of many piston and screw jack type controls manufactured by

Hobson

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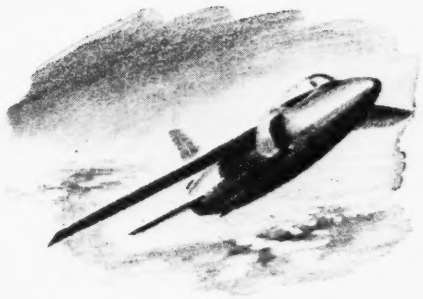
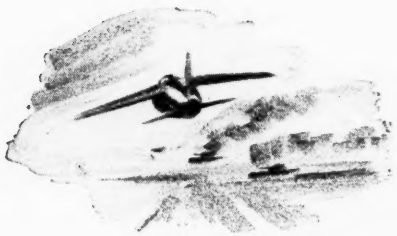
The Versatile GNAT

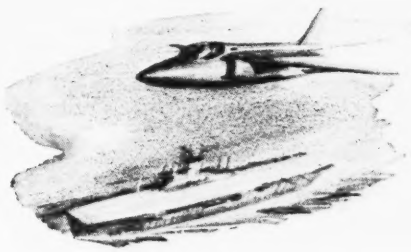
The Gnat, originally designed and built by Folland Aircraft as a "private venture" light interceptor fighter to meet the needs of countries which could neither build nor buy conventional fighters, is now available in three additional roles — fighter bomber, naval fighter and two-seat transonic trainer.

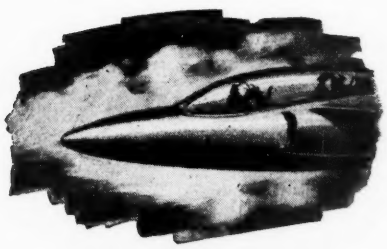




As a fighter bomber operating from temporary airstrips the Gnat can carry heavy loads of bombs and rockets on under-wing pylons. External tanks can be fitted to increase duration on low-level sorties.

In its carrier-borne role it has one hour's duration on internal tanks and two hours with under-wing tanks. It needs no wing folding and takes up so little stowage space that 14 can be stowed in the space occupied by five conventional naval fighters.





As a two-seater intermediate and advanced transonic trainer the Gnat bridges the ever-widening gap between *ab initio* and operational flying. It is fully aerobatic and carries fuel for a 75-minute training flight plan in internal tanks. Under-wing tanks give an additional 60 minutes' flying time if required.

All three versions have the same basic characteristics as the Interceptor Gnat — high performance, ease of handling, low maintenance time, low initial and operating costs — and all can be built wherever modern production facilities exist.

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President: J. C. CORBY, O.B.E.
Chairman: A. W. TURNER.
Hon. Secretary: B. V. POULSTON, Thornton Research Centre, P.O. Box 1, Chester.

CHRISTCHURCH
President: W. A. TAMBLIN, F.R.Ae.S.
Chairman: G. B. EVANS.
Hon. Secretary: H. E. VINCENT, A.F.R.Ae.S., de Havilland Aircraft Co. Ltd., Airspeed Div., Christchurch Aerodrome, Hants.

COVENTRY
President: H. M. WOODHAMS, C.B.E., F.R.Ae.S.
Chairman: W. J. PETERS.
Hon. Secretary: C. T. SCULTHORPE, A.F.R.Ae.S., Sir W. G. Armstrong Whitworth Aircraft Ltd., Baginton, Coventry.

DERBY
President: LORD HIVES, C.H., M.B.E., Hon.F.R.Ae.S.
Chairman: A. G. ELLIOTT, C.B.E., F.R.Ae.S.
Hon. Secretary: W. R. BENDALL, A.F.R.Ae.S., Rolls-Royce Ltd., Derby.

GLASGOW
President: Professor W. J. DUNCAN, C.B.E., F.R.Ae.S.
Chairman: D. B. SWINBANKS, A.F.R.Ae.S.
Hon. Secretary: Dr. A. W. BABISTER, A.F.R.Ae.S., Dept. of Aeronautics, The University, Glasgow, W.2.

GLOUCESTER AND CHELTENHAM
President: R. H. BOUND, F.R.Ae.S.
Chairman: J. F. CUSS, A.F.R.Ae.S.
Hon. Secretary: R. C. DELL, A.R.Ae.S., Dowty Equipment Ltd., Arle Court, Cheltenham.

HALTON
Chairman: Gp. Capt. A. K. HUNTER, O.B.E., A.F.R.Ae.S.
Hon. Secretary: Flt. Lt. B. D. AUSTEN, A.F.R.Ae.S., Apprentice Schools, R.A.F., Halton.

HATFIELD
President: Sir GEOFFREY DE HAVILLAND, C.B.E., A.F.C., [Hon.F.R.Ae.S.
Chairman: C. T. WILKINS, O.B.E., F.R.Ae.S.
Hon. Secretary: E. J. MANN, A.R.Ae.S., de Havilland Aircraft Co. Ltd., Hatfield.

HENLOW
President: Professor A. J. MURPHY, A.F.R.Ae.S.
Chairman: Group Captain W. F. BECKWITH, C.B.E.
Hon. Secretary: Sqn. Ldr. E. J. HOLDEN, R.A.F. Technical College Mess, Henlow, Bedfordshire.

ISLE OF WIGHT
President: Sir ARTHUR GOUGE, Hon.F.R.Ae.S.
Chairman: H. KNOWLER, F.R.Ae.S.
Hon. Secretary: L. W. ROSENTHAL, A.F.R.Ae.S., Saunders-Roe Ltd., Osborne, E. Cowes, Isle of Wight.

LEICESTER
Chairman: I. TORBE, A.F.R.Ae.S.
Hon. Secretary: R. G. AUSTIN, A.R.Ae.S., Helicopter Dept., Auster Aircraft, Rearsby, Leicester.

LUTON
President: W. A. SUMMERS, A.F.R.Ae.S.
Chairman: E. N. B. BENTLEY, A.F.R.Ae.S.
Hon. Secretary: L. A. WILLOTT, A.F.R.Ae.S. Hunting Percival Aircraft Ltd., Luton Airport.

MANCHESTER
President: Sir ROY H. DOBSON, C.B.E., J.P., Hon.F.R.Ae.S.
Chairman: C. E. FIELDING, O.B.E., F.R.Ae.S.
Hon. Secretary: J. A. E. WATERFALL. 56 Manor Avenue, Ashton-on-Mersey, Cheshire.

MERTHYR TYDFIL
President: W. R. MORGAN.
Chairman: J. INGRAM.
Hon. Secretary: G. M. MAGILL, A.F.R.Ae.S., Teddington Controls Ltd., Cefn Coed, nr. Merthyr Tydfil, South Wales.

PRESTON
President: Sir GEORGE H. NELSON.
Chairman: W. HARPLEY.
Hon. Secretary: E. LOVELESS, A.F.R.Ae.S., Aircraft Division, English Electric Co. Ltd., Warton Aerodrome, nr. Preston.

READING
President: Sir FREDERICK HANDLEY PAGE, C.B.E.,
Chairman: R. J. FENNER, A.F.R.Ae.S. [Hon.F.R.Ae.S.
Hon. Secretary: G. H. DAVIES, Grad.R.Ae.S., Handley Page (Reading) Ltd., The Aerodrome, Woodley, Reading.

SOUTHAMPTON
Chairman: H. C. SMITH, F.R.Ae.S.
Hon. Secretary: S. F. STAPLETON, A.F.R.Ae.S., Folland Aircraft Ltd., Hamble, Hants.

WEYBRIDGE
President: G. R. EDWARDS, C.B.E., F.R.Ae.S.
Chairman: H. H. GARDNER, F.R.Ae.S.
Hon. Secretary: E. G. BARBER, A.R.Ae.S., Vickers-Armstrongs (Aircraft) Ltd., Weybridge.

YEOVIL
President: E. C. WHEELDON.
Chairmen: D. L. HOLLIS-WILLIAMS, F.R.Ae.S., and Dr. E. W. STILL, F.R.Ae.S.
Hon. Secretary: L. A. LANSDOWN, A.F.R.Ae.S., Westland Aircraft Ltd., Yeovil.

Secretary's News Letter

October 1956.

IN 1954 when I was visiting New Zealand a member of the Society there asked me "Is Miss Betty Voyce still with you?" and I replied "Yes." For some time he reminisced concerning his early connection with the Society and how well-known Miss Voyce was to the apprentices and students of that earlier age.

Now I regret to say that Miss Betty Voyce has decided to resign from the Staff of the Society, of which she has been a member for more than 25 years. That she will be missed both by the Staff and by the Members is something which requires no emphasis; equally true is the fact that with her she carries the good wishes of us all.

When Miss Voyce joined the Society in 1928, about six months after she left school, there were only three others on the Staff besides the Secretary and little more than 1,000 members; today I have a total staff of 42 and there are over 8,500 members. As the Society has grown, so has Miss Voyce; from a junior whom everyone knew, doing jobs of all kinds—including by 1929, the Society's accounts, which then took about an hour a day only to do—to the Head of the Accounts Department with a staff of six. She has developed her capabilities in the service of the Society; time after time she has shown herself capable of meeting any emergency and her duties always have involved more than just the accounts and finances of the Society.

The Society, the Members and the Staff will miss her integrity and loyalty. The Staff particularly will miss her good humour, candour and common sense, her willingness to give help wherever possible. All will miss her for all had complete confidence in her.

I shall miss her also, for she has been of considerable assistance to me personally. I have her assurance that she will not be a complete stranger, so we shall hope to see her at Society functions and to hear how she fares.

On behalf of all the Members and of the Staff I wish her well wherever she goes. Good wishes go with her always.

A. M. Ballantyne

Secretary

NOTICES

An annual sum of £250 is available for premium awards for papers, including Technical Notes, published in the Journal. Members and non-members of the Society are invited to submit papers on any aspect of aeronautics

Royal Aeronautical Society Scholarships and Grants 1956/57

The following Scholarships and Educational Grants have been awarded by the Council:—

The Charter Scholarship.—G. E. Cook of Coventry for post-graduate work in Aerodynamics at Imperial College. He is 21 years of age and holds the degree of B.Sc.(Eng.) of London University.

The Edward Busk Studentship in Aeronautics.—R. W. Roberts of Birmingham for research work in Gas Turbine Aerodynamics for a Ph.D. degree at Imperial College. He is 27 years old and holds the degree of B.Sc. of the University of Cape Town, the Diploma of Imperial College (in Gas Turbine Technology) and has just completed the Thermodynamics Course for the M.Sc. degree of Birmingham University.

The Geoffrey de Havilland Memorial Scholarship.—D. M. Squires of Bishop's Stortford, to complete his course in Aircraft Propulsion at the College of Aeronautics, Cranfield. He is 23 years old and has already completed a five-year engineering apprenticeship with the de Havilland Engine Company.

Educational Grant.—M. G. Bader of Whetstone, N.20, to enable him to continue his research work on fatigue at Battersea Polytechnic. This will be the third year for which Mr. Bader has been awarded a grant by the Society.

Educational Grant.—T. J. Black of Dublin to enable him to continue his study for a Ph.D. in Aeronautics at Cambridge. He is 23 years old and was awarded the Charter Scholarship in 1955. Mr. Black holds the degree of B.Sc. of Belfast University and won a Whitworth Prize in 1953 and a Whitworth Scholarship in 1954. He has also served a four-year apprenticeship with Short Bros. and Harland Ltd.

Educational Grant.—E. M. Cowburn of N. Ferriby, E. Yorks, to enable him to complete his course for the Diploma of the College of Aeronautics, Cranfield. Mr. Cowburn was also awarded this grant in 1955/56. He holds the degree of B.Sc.(Eng.) of London University and has served a five-year apprenticeship with Blackburn and General Aircraft Ltd. He is 22 years old.

Educational Grant.—J. I. Dodds of Hull to enable him to continue his studies for a Ph.D. at Peterhouse, Cambridge. Mr. Dodds was awarded the Edward Busk Studentship in Aeronautics in 1955. He holds the B.A. degree of Cambridge where he took the Mechanical Sciences Tripos. He has had one year with Blackburn and General Aircraft Ltd., and is 22 years old.

Educational Grant.—D. J. Huggett of Carshalton Beeches, Surrey, to enable him to undertake a course of post-graduate study at Southampton University. He is 22 years old and holds the B.Sc.(Eng.) degree of London University. He has also served a five-year apprenticeship with Handley Page Ltd.

Educational Grant.—N. E. Phelps of London to enable him to take a post-graduate course in Aircraft Structures at Imperial College. He is 22 years old and holds the degree of B.Sc.(Eng.) of London University.

The Library

We regret that members could not be given advance notice of the closing of the Library for redecoration. It is hoped that it will be open again by the 9th October 1956.

Formation of a Branch at London Airport

The Council of the Society have given their consent to the forming of a Branch at London Airport and the formation and inaugural meeting was held on Tuesday 25th September 1956 at 17.45 hours in B.E.A.'s Viking Centre Cinema, Hatton Cross.

Mr. B. S. Shenstone, *Fellow* and Member of Council and Chief Engineer, B.E.A., was in the Chair, supported by Dr. A. M. Ballantyne, Secretary of the Society. At this meeting the Branch Officers and a Branch Committee were elected but, unfortunately, the information was too late to be included in this Journal.

The business side of the meeting was followed by an illustrated lecture by Mr. K. J. Anderson, Chief Technical Officer, British Aviation Insurance Company, entitled "Problems of Aircraft Recovery".

Royal Aeronautical Society Prize in Aeronautics

The Royal Aeronautical Society Prize in Aeronautics has been awarded to J. R. Hatfield, as the best student of the year in the 1955-57 Diploma Course at the College of Aeronautics.

"Transonic Wind Tunnel Testing Techniques"—All-Day Section Lecture and Discussion, Thursday, 20th December 1956

Admission by Special Ticket Only

On Thursday 20th December 1956 the Society is holding this all-day meeting at the Institution of Mechanical Engineers, starting at 10.00 hrs. The Chairman will be Major G. P. Bulman and five introductory papers will be read by Mr. H. F. Vessey, Mr. R. Hills, Mr. J. A. Kirk, Mr. F. O'Hara and Mr. F. E. Roe. This meeting promises to be of considerable interest to those involved in any way with the use of Wind Tunnels or the data provided by them.

To avoid disappointment and to ensure the admission of members wishing to attend, it has been decided that on 20th December *admission will be by special ticket only* for members and non-members alike.

Members: Tickets will be issued upon request to the Secretary to members of the Society *by name only* until Thursday 13th December, when any seats not taken will be made available to non-members.

Non-Members: No visitors' tickets will be issued before 13th December, one week before the lecture, when any seats not required by members will be made available to non-members. Requests should be sent to the Secretary as soon as possible as they will be dealt with in strict rotation.

The Secretary regrets that it is necessary to impose these restrictions but hopes that this arrangement will avoid inconvenience to members.

News of Members

Carl Agostini (*Associate*) Director of Civil Aviation, Trinidad has started on a year's mission as Civil Aviation Advisor to the Government of the Dominican Republic.

R. D. B. Archer (*Associate*) has left Canadair Ltd., Montreal and is now with Northrop Aircraft Inc., as a Designer.

Flight Lieut. J. N. Bean (*Associate*) has been appointed Group Technical Officer, No. 67 (Northern Ireland) Group, Royal Air Force.

Group Captain V. N. Bhardwaj (*Associate Fellow*) Director of Technical Services, Air Headquarters, India, has been seconded to Hindustan Aircraft Ltd., Bangalore.

A. E. Brock (*Graduate*) has left Vickers-Armstrongs (Aircraft) Ltd., to take up the post of Lecturer in Aerodynamics at the Northampton Polytechnic.

W. A. Burnside (*Associate*) has been appointed sales manager of R. B. Pullin & Co. Ltd., Brentford.

Sub. Lieut. D. P. Compley (*Graduate*), R.N.V.R., has been appointed to R.N.A.S. Ford, from the R.N. Engineering College, at Manadon.

A. H. Emden (*Associate*) has been appointed a Section Leader with Decca Radar Ltd., in their Development Drawing Office.

L. G. Frise (*Fellow*) formerly Technical Director of Hunting Percival Aircraft has been appointed to the newly created post of Director of Special Projects at Blackburn and General Aircraft Ltd.

J. B. Goodsir (*Associate*) has taken up the post of Head of the Technical Department, Grammar Technical School, South Shields, Co. Durham.

Flight Lieut. E. L. Gosling (*Associate*) formerly at Vickers-Armstrongs (Aircraft) Ltd., Supermarine Division is now employed by the U.K.A.E.A. Engineering Unit at Bracknell.

G. W. Hall (*Associate Fellow*) formerly Assistant Managing Director of Fairey Aviation Co., Ltd., has been appointed Managing Director in succession to Sir Richard Fairey (*Hon. Fellow*) who has resigned from that office.

J. Hall (*Associate Fellow*) formerly Development Engineer has been appointed Experimental Manager with Blackburn and General Aircraft Ltd.

J. M. Hardman (*Graduate*) has resigned his position as Deputy Research Engineer with Sir W. G. Armstrong Whitworth Aircraft to take up an appointment as Technical Officer (Engineer) with Imperial Chemical Industries.

R. Hawkins (*Graduate*) formerly with the National Gas Turbine Establishment is now a Senior Technical Engineer in the Ram-jet Development Department of Bristol Aero-Engines Ltd.

R. W. E. Hill (*Graduate*) has left de Havilland Aircraft Co., Ltd., at Christchurch to take up a post in the Stress Office of Avro (Canada) Ltd. at Malton, Ontario.

F. H. Hooke (*Associate Fellow*) has been given leave of absence for a year from the Aeronautical Research Laboratories, Melbourne, to accept the appointment of Senior Research Assistant to Professor Pope, Professor of Engineering at the University of Nottingham.

Wing Cdr. R. F. Jones (*Associate*) formerly Sqn. Ldr. serving in M.O.S. R.D. (L) is now serving as Senior Technical Officer at R.A.F. Oakington.

M. J. Kemper (*Associate Fellow*) will shortly take up the post of Senior Reactor Engineer at the Hawker Siddeley Nuclear Power Co.

H. McLennan Kendall (*Associate Fellow*) former Handley Page Test Pilot and lately designer and Pilot of the SK.1 has joined Shell-Mex and B.P. Ltd. on Technical Liaison work with airlines and the aircraft industry.

E. E. Labram (*Associate Fellow*) has accepted an appointment as an Engineer II at the Atomic Weapons Research Establishment, Aldermaston.

P. M. Lavelle (*Associate Fellow*) formerly an Experimental Officer at the Royal Aircraft Establishment has taken up an appointment as an Engineer III in the Reactor Division at the Atomic Energy Research Establishment, Harwell.

H. J. Lough (*Associate Fellow*) has left Bristol Aircraft (Western) Ltd. at Winnipeg and is now a Design Engineer with Lockheed Aircraft Corporation, Burbank, California.

C. S. R. Marshall (*Graduate*) has left for Canada where he is employed as a Design Engineer by Avro (Canada) Ltd. at Malton.

H. W. Pakes (*Graduate*) is now an Engineer in the Development Stress Office, English Electric Co. Ltd., Warton Aerodrome.

O. G. de S. Ricardo (*Associate Fellow*) is now an Associate Professor of Aircraft Structures at the Instituto Tecnologico de Aeronautica, the Aeronautical Engineering School of the Brazilian Air Ministry and is Acting Head of the Structures Department.

S. Scott Hall (*Fellow*) formerly Head of the Ministry of Supply Staff at the British Joint Services Mission in Washington has been appointed Scientific Advisor to the Air Ministry.

J. V. Stanbury (*Associate Fellow*) formerly Chief Project Engineer with Hawker Aircraft Ltd. is now Chief Designer in the Motor Car division of Rolls-Royce Ltd.

E. Szomanski (*Associate Fellow*) formerly a Senior Lecturer in Fluid Dynamics at the University of Tasmania has been appointed a Staff Research Engineer at Stratos Division, Fairchild Engine and Airplane Corporation.

Squadron Leader E. A. Tilt (*Associate Fellow*) R.A.F. (Retired) has taken up an appointment with Armstrong Siddeley Motors Ltd.

Lt. Cmdr. W. J. Tuck (*Associate Fellow*) has retired from the Royal Navy and has joined the de Havilland Engine Company as Chief Instructor of the Engine Instruction School.

W. E. Walker (*Associate Fellow*) is now a Gas Turbine Experimental Engineer with Solar Aircraft Co., San Diego.

S. G. Wheeler (*Graduate*) formerly with Air Service Training has taken up a post with Marshalls of Cambridge as a Project Designer.

J. E. D. Williams (*Associate Fellow*) has taken up a new appointment as Head of Planning and Development with El Al, Israel Airlines Ltd.

I. E. Woodroffe (*Associate Fellow*) is now a Senior Designer with the Rocket Division of Rolls-Royce Ltd.

Sir Frederick Handley Page

The Queen has approved the appointment of Sir Frederick Handley Page (*Hon. Fellow*) as her Majesty's Lieutenant for Middlesex in the room of Lord Latham, resigned.

A. M. Low and the Guided Missile

There is, at present, great interest in the history and origin of the Guided Missile and in this connection the pioneer work done by the late A. M. Low during the 1914-18 War is in danger of being lost to posterity.

It would seem that for the purposes of a projected book by American official quarters it is necessary to produce satisfactory documentation of Low's invention and any results gained. Should any member have, in his possession, material which would help or should any member know where such material might be found, the Secretary would be grateful to hear of it. References such as those that appeared in aeronautical magazines are known but it is documents, such as official papers of the Ministry of Munitions, dealing with the subject that are sought.

DIARY

LONDON

9th October

SECTION LECTURE.—The Pressure Jet Helicopter. A. Stepan. Library, 4 Hamilton Place, London, W.1. 7 p.m.

11th October

MAIN LECTURE AT HENLOW BRANCH.—Rocket Motors. S. Allen. Building 62, R.A.F. Technical College, Henlow. 8 p.m.

17th October

MAIN LECTURE.—The Importance of Time in Aircraft Manufacture. Air Cdre. F. R. Banks, C.B., O.B.E. The Institution of Mechanical Engineers, Birdcage Walk, London S.W.1. 6 p.m. (Tea 5.30 p.m.)

23rd October

SECTION DISCUSSION.—Functional Efficiency of Aircraft. Introduced by C. Abell, O.B.E. and Air Vice-Marshal A. F. Hutton, C.B., C.B.E., D.F.C. Library, 4 Hamilton Place, London W.1. 7 p.m.

6th November

MAIN LECTURE.—London Airport. Air Marshal Sir John D'Albiac, K.B.E., C.B., D.S.O. The Institution of Mechanical Engineers, Birdcage Walk, London, S.W.1. 6 p.m. (Tea 5.30 p.m.)

13th November

SECTION LECTURE.—Air Conditioning of Aircraft. Dr. E. W. Still. Library, 4 Hamilton Place, London W.1. 7 p.m.

20th November

SECTION LECTURE.—C. of A. Flight Testing. D. P. Davies. Library, 4 Hamilton Place, London W.1. 7 p.m.

22nd November

TWELFTH BRITISH COMMONWEALTH AND EMPIRE LECTURE.—Aeronautical Development in Australia and Its Potential Value to the British Commonwealth. L. P. Coombes, D.F.C. The Institution of Mechanical Engineers, Birdcage Walk, London S.W.1. 6 p.m. (Tea 5.30 p.m.)

GRADUATES' AND STUDENTS' SECTION

10th October

Service Flight-Testing of High-Speed Aircraft. Sqn. Ldr. P. D. Thorne. Library, 4 Hamilton Place, W.1. 7.30 p.m.

17th October

Visit to the Royal Aircraft Establishment, Farnborough.

30th October

Nuclear Power for Aircraft. E. P. Hawthorne. Library, 4 Hamilton Place, W.1. 7.30 p.m.

23rd November

The Effects of Kinetic Heating on Aircraft Structures. A. W. Kitchenside. Library, 4 Hamilton Place, W.1. 7.30 p.m.

30th November

Annual Dance.

BRANCHES

10th October

Christchurch.—The Design of a Fighter Aircraft. Technicians of de Havilland Aircraft Ltd., Town Hall, Christchurch. 7.30 p.m.

Luton.—The A.R.A. Transonic Tunnels. A. B. Haines. Lecture Hall, Luton Public Library. 7 p.m.

Reading.—C. of A. Flight Testing. D. P. Davies. Western Manufacturing (Reading) Ltd. Canteen. 6 p.m.

Southampton.—Aero-elasticity at High-Speed. E. G. Broadbent. Institute of Education, University of Southampton. 7 p.m.

Weybridge.—The Large Transport Helicopter. Dr. G. S. Hislop. Apprentice Training School, Vickers-Armstrongs (Aircraft) Ltd., Weybridge. 6 p.m.

11th October

Bristol.—Presidential Address. Dr. A. E. Russell, C.B.E. Conference Room, Filton House, Bristol Aeroplane Co. 6 p.m.

Henlow.—MAIN LECTURE: Rocket Motors. S. Allen. Building 62, R.A.F. Technical College, Henlow. 8 p.m.

13th October

Halton.—Annual General Meeting 3.30 p.m. and Dinner 8 p.m. Branch Hut, R.A.F. Halton.

Luton.—Visit to Aircraft Research Association, Bedford.

15th October

Halton.—Film: The War in the Air Series No. 7. Branch Hut, R.A.F. Halton. 6.45 p.m.

16th October

Belfast.—Soaring Flight. A. H. Yates. Kensington Hotel, Belfast. 7 p.m.

17th October

Coventry.—Problems Associated with Production and Use of Wrought Aluminium Alloys. G. Forrest and K. Gunn. Wine Lodge, The Burges, Coventry. 7.30 p.m.

Leicester.—Atomic Energy for Aircraft Propulsion. J. E. Perkins. Loughbrough College, Leicester. 6.30 p.m.

18th October

Isle of Wight.—The 1956 World Gliding Championships. P. Wills. Clubhouse, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6.30 p.m.

Southampton.—Plastics: Materials, Processes, Machines. D. C. Nicholus (with Institute of Production Engineers) Polygon Hotel, Southampton. 7.15 p.m.

22nd October

Glasgow.—Development of the Jet Propulsion Gas Turbine. G. C. R. Mathieson. Royal Technical College, Glasgow. 7.15 p.m.

Henlow.—Descent from Space. T. R. F. Nonweiler. North Beds. College of Further Education, Bedford. 7.30 p.m.

23rd October

Halton.—Film: The War in the Air Series No. 8. Branch Hut, R.A.F. Halton. 6.45 p.m.

24th October

Bristol.—Britannia Brains Trust. Conference Room, Filton House, Bristol Aeroplane Co. Ltd. 6 p.m.

Luton.—Junior Night—Any Questions Brains Trust and Discussion. Napier Senior Staff Canteen, Luton Airport. 6.15 p.m.

29th October

Halton.—Film: The War in the Air Series No. 9. Branch Hut, R.A.F. Halton. 6.45 p.m.

31st October

Christchurch.—Ejection Seats, The First Decade. J. Jewell. Town Hall, Christchurch. 7.30 p.m.

Reading.—The Rolls-Royce Dart Engine for Civil Aircraft: Some Design Considerations. R. J. Shire. Western Manufacturing (Reading) Ltd. Canteen. 6 p.m.

Southampton.—Airline Operation and Maintenance. C. Abell. Institute of Education, University of Southampton. 7 p.m.

Weybridge.—R. K. Pierson Memorial Lecture. N. E. Rowe. Apprentice Training School, Vickers-Armstrongs (Aircraft) Ltd., Weybridge. 6.p.m.

5th November

Halton.—Film: The War in the Air Series No. 10. Branch Hut, R.A.F. Halton. 6.45 p.m.

Belfast.—Gyroscope. C. B. Flindt. Kensington Hotel, Belfast. 7 p.m.

6th November

Boscombe Down.—High-Speed Flight Problems. R. F. Creasey. Lecture Hall, A. and A.E.E., Boscombe Down, Amesbury. 5.45 p.m.

7th November

Bristol.—The Dawn of Aerodynamics. J. Laurence Pritchard. Conference Room, Filton House, Bristol Aeroplane Co. 6 p.m.

Chester.—Flight Systems for Transport Aircraft. W. H. McKinley. Grosvenor Hotel, Chester. 7.30 p.m.

Luton.—The Prestwick Pioneer. N. J. Capper. Napier Senior Staff Canteen, Luton Airport. 6.15 p.m.

8th November

Isle of Wight.—Annual Dinner.

12th November

Glasgow.—Uses of Electronic Computing Machines. R. J. A. Paul. Royal Technical College, Glasgow. 7.15 p.m.

Halton.—Film: The War in the Air Series No. 11. Branch Hut, R.A.F. Halton. 6.45 p.m.

Henlow.—The Use of Plastics in the Aircraft Industry. H. V. Potter. Building 62, R.A.F. Technical College. 7.30 p.m.

16th November

Birmingham.—Silencing of Jet Engines. F. B. Greatrex. Birmingham Engineering Centre, Stephenson Place, Birmingham. 7.15 p.m.

Luton.—Branch Dinner. Leicester Arms Hotel, Luton.

19th November

Halton.—Film: The War in the Air Series No. 12. Branch Hut, R.A.F. Halton. 6.45 p.m.

21st November

Bristol.—Junior Members' Papers Competition. Conference Room, Filton House, Bristol Aeroplane Co. Ltd. 6 p.m.

Christchurch.—Aeroplane Noise: A Challenge. Professor E. J. Richards. Ball Room, Kings Arms, Christchurch. 7.30 p.m.

Coventry.—Some Influences of Equipment and Systems on Aircraft Design. C. F. Joy. The Wine Lodge, The Burges, Coventry. 7.30 p.m.

Reading.—Interplanetary Flight. J. Humphries, Western Manufacturing (Reading) Ltd. Canteen. 6 p.m.

Weybridge.—New Machining Techniques in the Aircraft Industry. L. G. Burnard and T. A. Waite. Apprentice Training School, Vickers-Armstrongs (Aircraft) Ltd. 6 p.m.

26th November

Bristol.—Visit to Engineering Faculty, University of Bristol.

Henlow.—Meteorology: Clear Air Turbulence. Dr. R. S. Scorer. Building 62, R.A.F. Technical College, Henlow. 7.30 p.m.

27th November

Boscombe Down.—Aeroplane Noise: A Challenge. Professor E. J. Richards. Lecture Hall, A. and A.E.E., Boscombe Down, Amesbury. 5.45 p.m.

NOTE: *Branch Honorary Secretaries are reminded that information about meetings for the November Diary must be received by 15th October. Time and place at which meetings are held should be included, please.*

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Alexander Lovell Parker
James Antony Rowland (*from Graduate*)
Harold Alexander Simon (*from Graduate*)
Sydney William White (*from Graduate*)

Associates

Ronald Adams
Cyril Aubrey Glew (*from Graduate*)
Alastair John Macdonald (*from Graduate*)
John Joseph McDonald
Frederick Arthur Roper
Frederick Charles Hector Taylor

Graduates

Keith Hind (*ex-Student*)
Arnold Roberts

Students

John Robert Andrew
Banarsi Lal Awasthi
George Eric Deadman
Gerald Hill
Robert Charles Ingall
John Robert Lyon
Roger Martin Wistow Manning
Barrie John Thomas
Frank Thomas Wilson

KING GEORGE VI MEMORIAL FELLOWSHIPS

Sponsored by the English-Speaking Union of the United States, between 25 and 30 King George VI Memorial Fellowships will be awarded for 1957-58 in two categories: graduates of British universities who wish to take post-graduate courses at American universities and students of British technical colleges who wish to take courses at similar institutions in the U.S. The stipend of each fellowship will be $2,500 plus the cost of tuition and the minimum cost of travel. All candidates must be:—(*a*) Citizens of the United Kingdom or Northern Ireland, either by birth or naturalisation. (*b*) Holders of a British University degree, or candidate for such a degree in the summer of 1957 (first category), holders of a Higher National Certificate, or candidates for such a Certificate in the summer of 1957 (second category). (*c*) Not less than 18 nor more than 30 on 31st August 1957. (*d*) Unmarried.

Application forms and full particulars may be obtained from Mrs. D. R. Dalton, B.A., King George VI Memorial Fellowship Committee, 37 Charles Street, Berkeley Square, London, W.1. Completed forms must be returned *by 10th November* 1956.

COMMONWEALTH FUND FELLOWSHIPS 1957

Six categories of Fellowships of the Commonwealth Fund, New York, are open to British subjects (men and women) who are not normally resident in or near the Americas and who have not previously worked or studied for more than a few months in the United States. The Fellowships provide for all expenses of travel, study, and living. Some adjustment of Fellowship stipends is made to enable married men to become candidates.

GENERAL.—Twenty Fellowships are offered to degree graduates of a university in the United Kingdom of Great Britain and Northern Ireland. Candidates must be available in London for interview in March 1957. Age: 23 to 32. Tenure: twelve to twenty-one months. Closing date of applications: 15*th December* 1956.

HOME CIVIL SERVICE.—Five Fellowships are offered to permanent members in the higher ranks of the Civil Service in Great Britain, three for the administrative grades and two for the scientific and professional grades. Age: preferably under 40. Tenure: nine to fifteen months. Closing date of applications: 10*th December* 1956, to the Treasury.

AUSTRALIAN AND NEW ZEALAND CIVIL SERVICES.—Five Fellowships are offered to civil servants in the Governments of Australia and New Zealand. Age: under 40. Tenure: nine to fifteen months. Closing date of applications: 1*st November* 1956. Australian applications to Dr. H. Carlyle Forster, Box 4079, Melbourne; New Zealand applications to the Public Service Commission, Wellington.

OVERSEA CIVIL SERVICE.—Two Fellowships are offered to civil servants in the Governments of British Colonies, Protectorates, and Trust Territories. Age: under 40. Tenure: nine to fifteen months. Closing date of applications: 17*th November* 1956, to the Colonial Office, London.

JOURNALISM.—Three Fellowships are offered to journalists, practising in the United Kingdom and engaged on the opinion-making or broadly editorial side of their profession. Age: 23 to 35. Tenure: nine to fifteen months. Closing date of applications: 31*st December* 1956.

AMERICAN STUDIES.—Four Fellowships will be available to faculty members appointed to or holding posts in American studies in universities in the United Kingdom; candidates to be nominated by their universities. Tenure: four to fifteen months. These Fellowships are not limited by previous study in the United States.

Full particulars may be obtained from The Warden, Harkness House, 35 Portman Square, London W.1.

The Greer Awards

Two international awards, a Public Relations Award and a Maintenance Award, have been established by Greer Hydraulics, Inc. of New York. The Awards are intended to stimulate world-wide thought and action that will benefit the entire Aviation Industry and the public by encouraging solutions to a major Public Relations problem confronting the Industry; and solutions to a troublesome Aircraft Maintenance problem.

The Maintenance Award will be presented annually, in the form of a plaque and an honorarium of $500, for the best idea, proposal or design leading to the solution of an aircraft maintenance problem. The Public Relations Award will be made for the outstanding contribution to the suppression of noise from jet aircraft between now and 1958. The Award, consisting of a plaque and an honorarium of $1,000, will be presented late in 1958.

Any individual, group of individuals, company, association or military establishment is eligible for both Awards. Entries may be in the form of an entirely original idea, a published article or a manuscript now being considered for publication. Any idea, proposal or design etc., may be an entry as long as it meets the requirements of either Greer Award. Entry forms may be obtained from Greer Hydraulics, Inc., N.Y. International Airport, Jamaica 30, New York.

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Members are reminded that their annual subscriptions become due on 1st January 1957. The rates are:—

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* Any Associate elected before 1st October 1947 may, if he wishes, elect not to receive the Journal, and in this case his subscription will be reduced by £1 1s. 0d. to £2 2s. 0d.

It will avoid delay and confusion if members, when sending remittances for subscriptions, will state their names clearly and give their addresses and grades of membership. Remittances should be made payable to the Royal Aeronautical Society.

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To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address. He would also like to know of any change of appointment.

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The Journal of the Royal Aeronautical Society

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

VOLUME 60 OCTOBER 1956 NUMBER 550

Problems Associated with the Production and Use of Wrought Aluminium Alloys

by

G. FORREST, B.Sc., A.M.I.Mech.E., A.F.R.Ae.S. and K. GUNN, B.Sc., A.R.S.M.

(*Aluminium Laboratories Ltd., Banbury*)

The 988th Lecture to be given before the Society and the 25th Main Lecture to be held at a Branch of the Society, "Problems Associated with the Production and Use of Wrought Aluminium Alloys," by G. FORREST, B.Sc., A.M.I.Mech.E., A.F.R.Ae.S., and K. GUNN, B.Sc., A.R.S.M., was held under the auspices of the Belfast Branch on 5th April 1956. Mr. D. KEITH-LUCAS, F.R.Ae.S., Chairman of the Belfast Branch, opened the proceedings, and Mr. E. T. JONES, C.B., O.B.E, M.Eng., F.R.Ae.S., presided for the rest of the meeting.

Mr. KEITH-LUCAS (*Branch Chairman*): This was a great occasion for the Belfast Branch because for the third time they were honoured to be the hosts of the parent Society, the Royal Aeronautical Society. It was with great pleasure that he welcomed their guests. First of all, Mr. E. T. Jones, the President-elect of the Royal Aeronautical Society, Dr. Ballantyne, the Secretary, and Mr. Dunsby and Mr. Simmons, both of the Technical Department, of the Society. The President, Mr. N. E. Rowe, and the Chairman of the Branches Committee, Mr. Handel Davies, had both sent their sincere apologies that they were unable to be present.

He would also like to extend a special welcome to three members of the Preston Branch, Mr. Turner, Mr. Swales and Mr. Dyson. They were rather "out on a limb" in Belfast, rather far from other Branches and they did appreciate this neighbourly gesture from the Preston Branch. He would also like to welcome their own President of the Belfast Branch, Sir Matthew Slattery, and their Vice-President, Mr. C. P. T. Lipscomb.

But this was essentially a Royal Aeronautical Society function and not a Belfast Branch function. Therefore he would invite Mr. E. T. Jones, the President-elect of the Royal Aeronautical Society, to take the Chair and to conduct the meeting.

Mr. E. T. JONES: It was a great pleasure and honour to be in Belfast that evening deputising for Mr. Rowe. They had already heard from Mr. Keith-Lucas that Mr. Rowe was unable to be present and he had asked him also to express his regrets.

People working in aeronautics were sometimes liable to overlook the fact that materials had played a tremendous part in the advancement that they had achieved. They knew that the aerodynamicist, the structural engineer, the propulsion engineer, had all made their mark on the progress of aviation but they must not forget that materials had forged a very great key towards the progress which had been made. Indeed he recollected that Sir Harry Garner, in his Wilbur Wright Lecture in 1952, made the statement that he doubted whether the Aircraft Industry today could make a much more forward aeroplane than the Wright Brothers did in 1903 if they were confined to the use of the same materials and to the same stalling speed. He thought that statement would have been a very profound one even if stalling speed had been left out. If one considered the materials that people in those days had to work on it was wonderful that they flew at all. Thus he thought it was fitting that they should have a lecture of the kind Mr. Forrest and Mr. Gunn were to give.

He had a pleasant duty to introduce the lecturers. Mr. Forrest was educated at London University and joined the National Physical Laboratory in 1925, or thereabouts, in the Engineering Division. In 1936 he joined the Northern Aluminium Company and he later transferred to the Aluminium Laboratories Ltd. He was now an Associate Director of Research in the Aluminium Laboratories Ltd. at Banbury. Mr. Forrest had impressed upon him that he should make a point of saying Banbury because there were three Laboratories of the firm. Mr. Gunn was educated at the Royal School of Mines. He joined the Northern Aluminium Company in 1944 and he too transferred to the Aluminium Laboratories in 1946. He did not know quite how they proposed to deal with the Lecture, but he thought that Mr. Forrest would read it and both would be available to reply to the questions.

1. Introduction

The manufacturer of aluminium alloys is required by the Aircraft Industry to produce material which conforms to specification requirements, and is reasonably uniform in that properties obtained on small samples are representative of comparatively large batches. In general, the specifications require a product to conform to certain standards of chemical composition, tensile properties, surface finish and shape, which last includes straightness or flatness. In addition the product is expected to be reasonably free from defects. There are, however, other properties expected of a material which are not included in the normal specifications, such as resistance to corrosion and stress corrosion and good fatigue strength; also in this category is a factor which has come to the fore in late

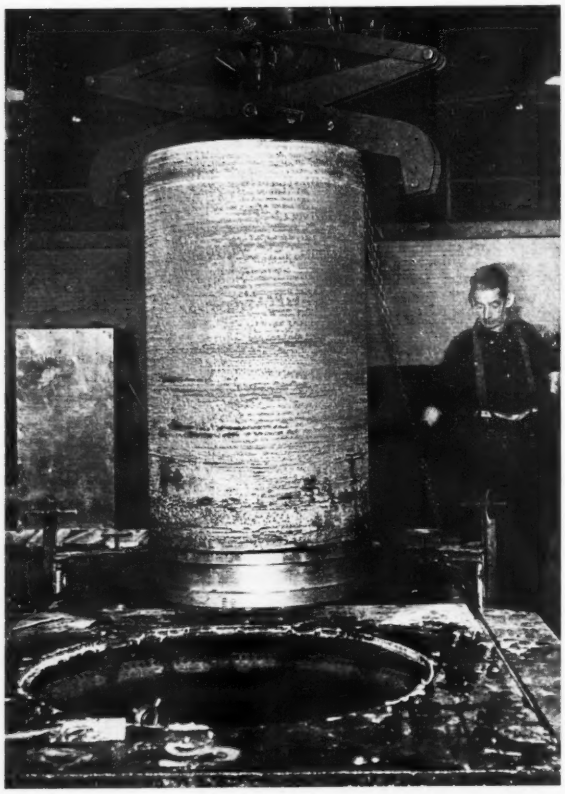

FIGURE 1. Cast billet 32 in. diameter by 60 in. long being removed from CCP casting unit.

years, namely that the product shall be substantially free from residual stresses so that it shall not distort unduly when it is machined.

The problems which face a manufacturer in meeting these requirements form the subject of this paper. It is possible to approach this matter from two different directions, the first being to study the properties required, one by one, and then to indicate how production variables will affect each. The other is to deal with each stage of production and show how it influences the properties. The latter approach is the one which has been adopted.

The first operation in the production of wrought alloys which need be considered in the present context is remelting. This involves commercial purity aluminium ingot and process scrap being melted together with the necessary alloying elements, to give an alloy of the correct nominal composition. The molten metal is then cast into ingots for rolling and billets for extrusion or forging. The ingots and billets are given a high temperature soaking treatment before being rolled, extruded or forged. Extrusion and forging are completed at high temperatures but the final rolling operations are usually done at room temperature. The alloys which respond to heat treatment are, in their finished form, heated to a high temperature, usually between 440°C and 530°C, quenched, generally in cold

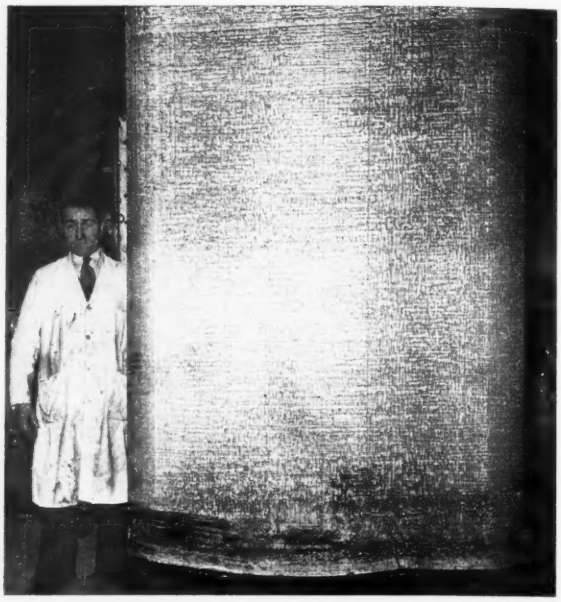

FIGURE 2. Cast ingot 60 in. wide by 12 in. thick by 87 in. long. (The small crack at the lower end of the ingot would be removed when the ingot is cropped before rolling.)

water but sometimes less severely, and then those which are amenable to artificial ageing are heated to temperatures between 120°C and 200°C. These processes are described in more detail later, with particular attention to the effects of the various procedures on the properties of interest to the aircraft manufacturer.

2. Remelting and Alloying

To ensure an adequate degree of uniformity of composition throughout the bath of molten metal in the remelt furnace, the metal must be thoroughly stirred. Stirring, however, disperses throughout the bath oxide skins resulting from the remelting process. This unfortunate result can be rectified by subsequent treatment of the molten metal with an active gas, such as chlorine, or by fluxes containing chlorides and fluorides.

Also of interest at this stage is the presence in the molten metal of an appreciable amount of dissolved hydrogen which is formed by reaction between molten aluminium and water vapour in the atmosphere of the furnace. If appreciable gas were to remain in the liquid metal the change in solubility upon solidification would result in the excess gas being thrown out of solution, and being trapped as bubbles in the pasty zones of the solidifying metal[1]. These bubbles of gas are flattened by mechanical work, such as rolling, so that whereas they are of negligible thickness they are of appreciable area. The flattened porosity may be a contributory cause of transverse weakness and low transverse ductility in the final product. Elimination of hydrogen is generally carried out by bubbling chlorine through the molten metal. The action is chiefly a physical one in that the removal of the gas will depend on its partial pressure in the chlorine bubbles.

3. Casting

The casting process is an extremely important stage in the production of wrought material as many of the characteristics of the final product are determined by the technique and standard of casting. The two factors which can be most easily varied during casting are the pouring rate and the cooling speed.

The majority of billets and ingots (Figs. 1 and 2) cast for subsequent working operations are cast by the direct chill, or as it is sometimes called, the continuous or semi-continuous casting process (CCP). (*See* Fig. 3). In this process the metal is poured into a shallow water cooled sleeve mould which surrounds a platform which can be lowered below the mould. The metal solidifies in the mould and the platform is lowered at a rate such that the level of the molten metal in the mould can be maintained constant by the addition of more molten metal. Further chilling is done by spraying water on the sides of the casting as it leaves the mould. The pouring is continued until the platform has descended to its lowest level. It should be mentioned at this stage that during solidification of most alloys there is an appreciable difference between the temperature at which the first solid metal separates from the liquid and the temperature at which solidification is complete. This results in a " pasty " region as shown in the diagram.

The main characteristics required of a good casting are that it should be free from oxide inclusions, cracks and porosity due either to shrinkage or to gas, and that it should have a fine and uniform structure. These requirements are often conflicting, so in many cases the casting technique must, to some extent, be a compromise[1].

Regarding oxide inclusions, molten aluminium forms a tenacious oxide skin very quickly when its surface is exposed to the air. Attention must be paid to this factor, since if the skin is broken, fragments may be entrapped within the casting. In all aluminium casting processes the pool of molten metal in the mould is kept quiescent and the oxide skin forms a more or less stationary envelope to the molten aluminium pouring stream. If the pouring rate is erratic and does not steadily keep pace with the rate at which the casting table is lowered, there is danger of entrapping oxide skin at the edge of the molten pool. If the pouring rate is too slow and the cooling speed too fast, the surface of the pool may solidify and be covered by a fresh layer of molten metal and the oxide skin on the solidified crust will be embedded in the casting.

These defects, known as " cold shuts," are normally removed by machining the surface of the castings, but on occasion they run deep into the metal and may give rise to flaws in the wrought products, for example they are one of the sources of sub-surface defects in extrusions and flash line defects in forgings. The molten metal must therefore be poured steadily and faster than a certain minimum rate.

Shrinkage porosity, on the other hand, is aggravated by high rates of casting and also by low cooling speeds since these tend to increase the extent of the pasty region. With an extensive pasty region there is less opportunity for molten metal to " feed-in " and prevent shrinkage cavities forming—the shrinkage cavities are due to the change in volume when molten aluminium solidifies. The range of solidification temperatures, and

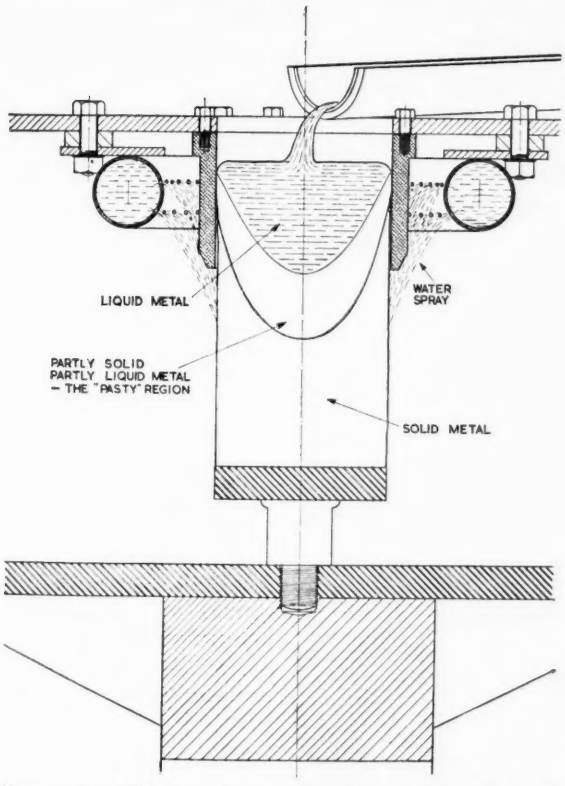

FIGURE 3. Diagrammatic representation of the continuous casting process.

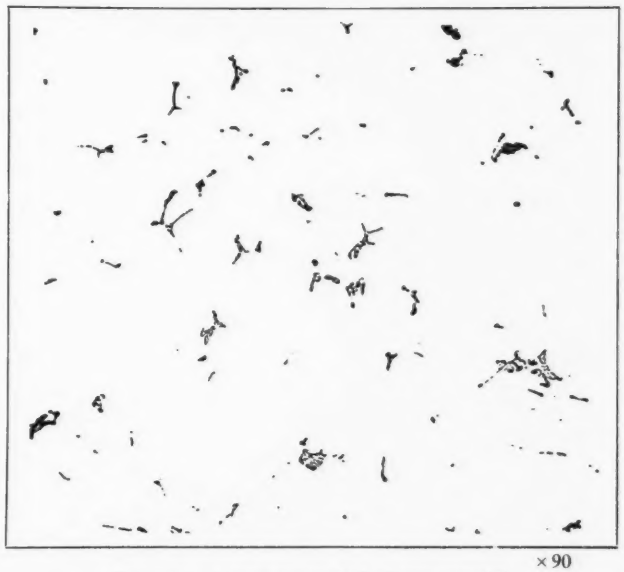

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FIGURE 4. A structure typical of cast material. B.S. L.65 composition.

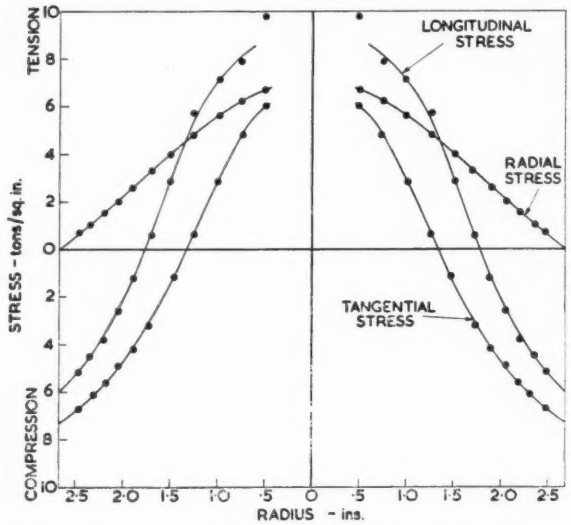


FIGURE 5. The residual stress distribution in a billet of D.T.D. 364B composition cast by the continuous casting process. (Ref. 2)

thus the distance between the boundaries of the pasty regions in castings, are not constant for all alloys and so it is to be expected that porosity is more prevalent in some alloys than in others.

Figure 4 shows a structure typical of cast material. The structure of the casting—that is the grain size and shape and the size and distribution of intermetallic constituents—usually becomes finer with faster cooling rates. It is usually an advantage to have a fine structure in a casting since it facilitates further working operations and may even be essential for some difficult operations. The chief reason for preferring a fine structure is the improvement in some of the final properties with which it is associated, due both to the ease of solution of intermetallic constituents during heat treatment and to the more uniform dispersion of the insoluble intermetallics.

Further complicating the casting process are the various systems of thermal stresses which arise during solidification and cooling. During and after solidification, the outside of the casting is cooled first. This cooling will cause the material to attempt to contract round the hot inside and, since it is "hot-short" at temperatures just below the melting point, there is danger of surface cracking occurring due to the resultant tensile stresses. These hot cracks may or may not propagate through the casting to the molten interior. Once the casting has cooled so that the outside skin is cold enough to withstand high stresses a stage is reached when the hot interior has become solid and, in trying to shrink, induces within itself tensile stresses and so again the casting can crack, this time in the middle of the billet. A crack-free casting when cold will contain high residual stresses, compression on the outside and tension in the interior due to the interior shrinking from the relatively rigid surface during cooling. (Fig. 5). These residual stresses may be sufficiently high to cause the casting to crack on standing at room temperature, probably because of minor fluctuations in the ambient temperature. Castings may also crack when being sawn to length, and to reduce the prevalence of this form of cracking it is often necessary to stress relieve the casting by soaking at elevated temperatures when the mechanical strength of the metal is low and, as a consequence, the residual stresses are relieved by plastic flow. That cast billets, particularly those continuously cast, contain high residual stresses has been shown by Mackie[2] and by others[3]. The stresses at the outside of the castings are limited in magnitude to the yield strength of the material, but in the middle there is no upper limit to the maximum stress, except by fracture of the material, since triaxial stresses are present. These internal stress systems become more severe with increase of cooling speed and also with increase in pouring rate.

These comments on the casting process are summarised in Table I, where the casting procedures resulting in various faults are given.

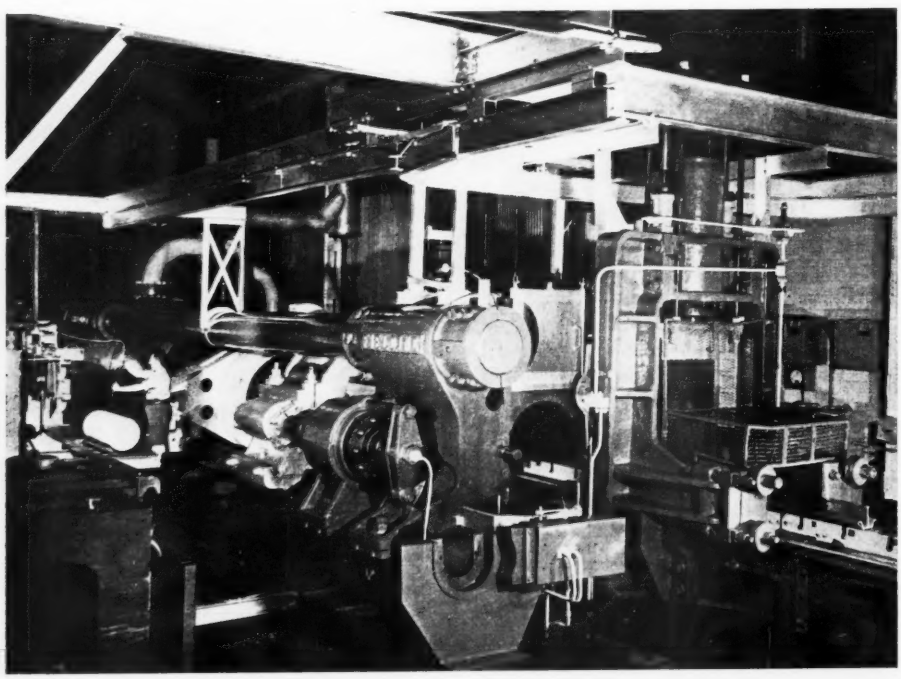


FIGURE 6. 7,500 ton extrusion press. A large section is being extruded.

TABLE I

CASTING PROCEDURES AND THEIR ASSOCIATED FAULTS

Casting Procedure	*Fault*
Slow pouring rate Fast cooling speed	Cold shuts
Fast pouring rate Slow cooling speed	Shrinkage porosity
Slow cooling speed	Coarse metallographic structure
Fast pouring rate Fast cooling speed	Stress cracking

In practice, above a critical size of billet, the main controlling factor in the casting process is the stress cracking. This is to say, casting is done as fast as possible and with the maximum cooling which does not result in excessive wastage of billets due to cracking. These speeds, however, are still sufficiently slow when casting large billets to cause in some alloys, undesirably coarse metallographic structures.

4. Mechanical Working or Forming

Wrought products are classified according to the method of working, namely extrusions, rolled products and forgings, and it is convenient at this stage to deal with each class separately.

(1) *Extrusions*

A general view of an extrusion press is shown in Fig. 6. An extrusion is normally made by placing a pre-heated cylindrical billet of the alloy in a cylindrical container, one end of which contains a die while the other end is open to receive a hydraulic ram. The die has an orifice machined to the shape of the required extruded section. The ram presses the material in the container and forces it through the hole in the die. So far the process appears simple. The complication begins when the actual flow of metal during the process is considered. The flow of metal through the die does not follow a simple pattern since the billet and container interface is not lubricated. The illustration in Fig. 7 shows a partially extruded billet which had previously been cut longitudinally into two halves and a grid scribed on one half; after the billet was half extruded to round bar, it was withdrawn from the container and split open. The flow during extrusion is shown clearly in Fig. 8 where every fifth grid line only is shown.

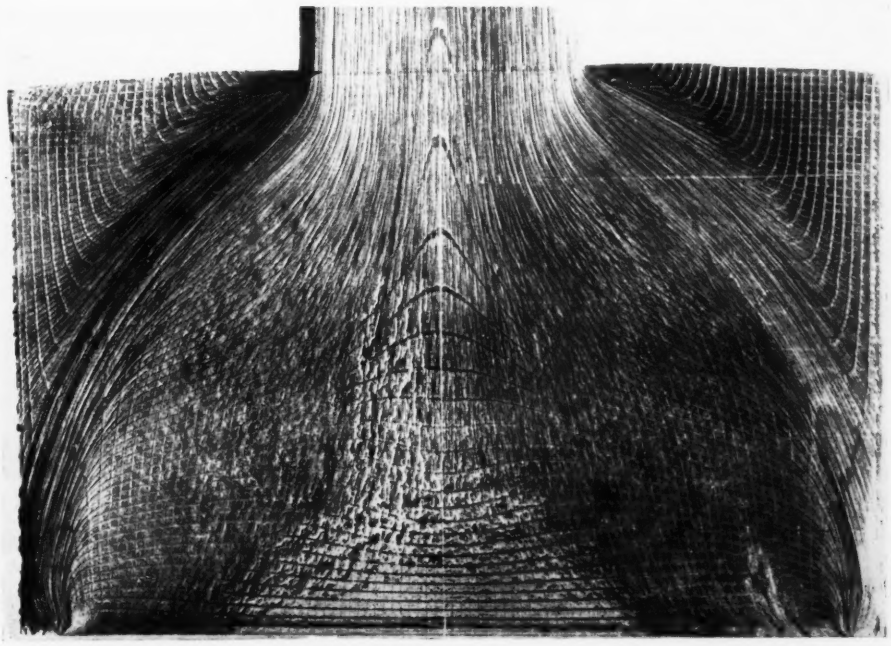
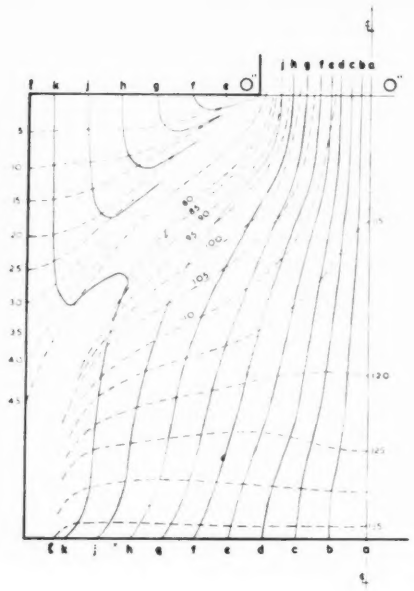


FIGURE 7. Metal flow in an unlubricated billet during extrusion.

It can be seen in the illustration that there is a " dead metal " zone at each side of the die where there has been no distortion of the grid. Near the die immediatetly adjacent to the " dead metal " zone is a very severely worked region but farther in towards the middle there is a less severely worked region, although the strain is still quite high. An estimate of the distribution of strain from the flow lines in the previous illustration is shown in Fig. 9 where it can be seen that near the centre of the section the material has been extended ninefold for this particular extrusion, but near the outside the strain is very great. This outer region forms very large crystals which may be due to the considerable degree of preferred orientation resulting from the high strains imposed on the outer band. This outer band when fully recrystallised has lower tensile and may have lower fatigue properties in the direction of extrusion than the finer grained core. The depth of the recrystallised outer band is partially related to the chemical composition of the alloy and varies to some extent with extrusion technique, which latter includes control of temperature during extrusion, speed of extrusion and die design.

In the previous diagram showing the flow lines, Fig. 8, it can be seen that at the front end of the extrusion the grid has been only slightly distorted and, as might be expected, the cast structure is not broken down. It is therefore necessary for the manufacturer to cut from every extrusion a small portion of the front end in which the mechanical properties are inadequate. The metal flow during extrusion does not reach a steady state and the thickness of the severely worked region near the outside of the extrusion usually increases as extrusion proceeds, and begins to be appreciable about half way along its length. As a result, the thickness of the coarse grain outer band in the finished extrusion also increases



towards the back end and eventually a stage is reached at which the amount is excessive and the material beyond this point also has to be discarded.

Of recent years attempts have been made to produce "lubricated" extrusions using both metallic[4] and non-metallic lubricants[5]. The flow during extrusion under these conditions and using a specially shaped container-die assembly is much more nearly uniform over the section than in the unlubricated case. (*See* Fig. 10). The resulting extrusion is therefore free from coarse grain outer band on heat treatment. Experimental work on aluminium alloys, however, has shown that the process has certain drawbacks which have not so far been overcome, so the process cannot at present be applied to routine production.

With the normal "unlubricated" extrusion process, an advantage of the metal flow is that the surface of the extrusion comes from a small volume of material in the interior of the billet so that it is not affected by imperfections in the original billet surface.

The rate and temperature at which extrusion is carried out vary widely with alloy composition, but with

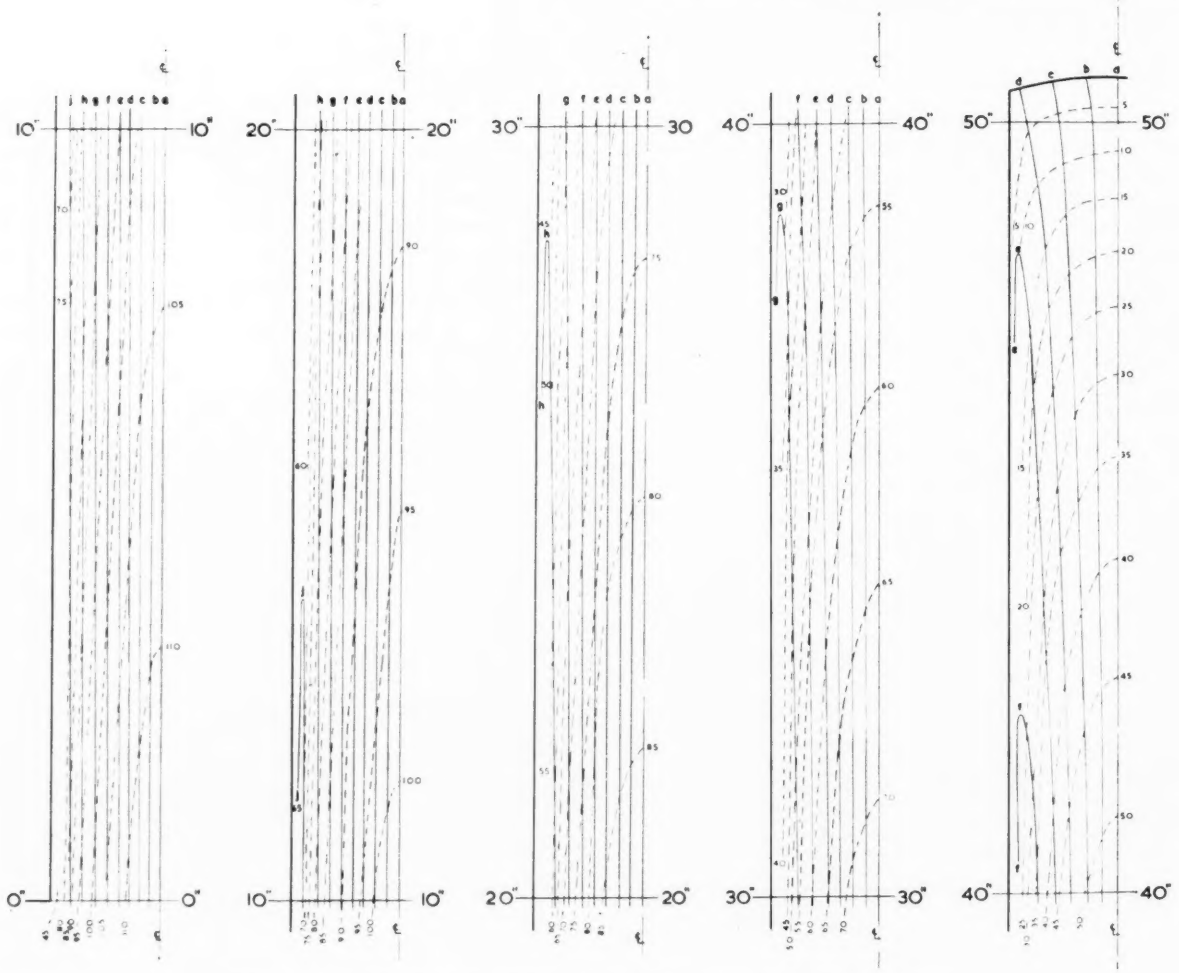


FIGURE 8. The distorted grid pattern in a split billet after unlubricated extrusion.

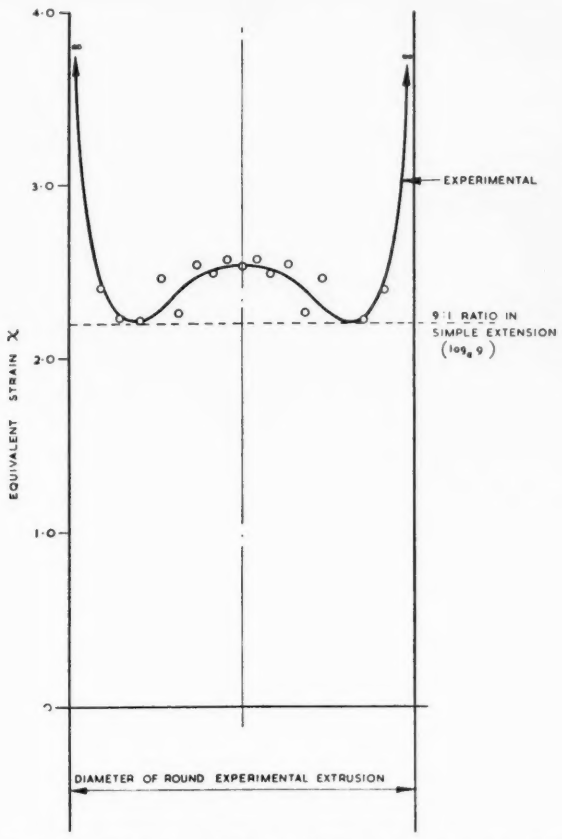


FIGURE 9. The total equivalent strain across a transverse section of a 3 in. diameter bar extruded from a 9 in. diameter billet. The equivalent strain can be compared directly with simple extension in a tensile test.

each alloy both must be carefully controlled to avoid an excess of outer band and general break up of the surface. An example of the latter, known as cross hatching, is shown in Fig. 11; cross hatching is due to

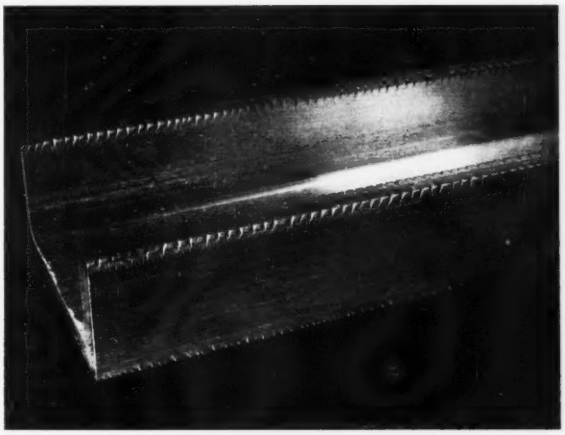


FIGURE 11. Cross-hatching at corners of an extruded channel section.

too high a temperature of metal as it leaves the die which in turn may be caused by too high a speed of extrusion.

Apart from the particular effects already mentioned, the general effect of the extrusion process is to elongate the material in one direction so that appreciable preferred orientation occurs throughout the section; intermetallic and non-metallic particles (not necessarily deformed themselves) become broken up and form "stringers" (*see* Fig. 12), and other forms of discontinuity become elongated either to needle-shaped or plate-shaped form according to the shape of the extrusion. Thus an extrusion may be expected to show pronounced directional properties—a point which will be considered later. The effects of extrusion on shrinkage porosity and oxide films may be very beneficial since, with the former, cavities may be flattened and the faces welded, while the latter may be broken up into extremely small particles.

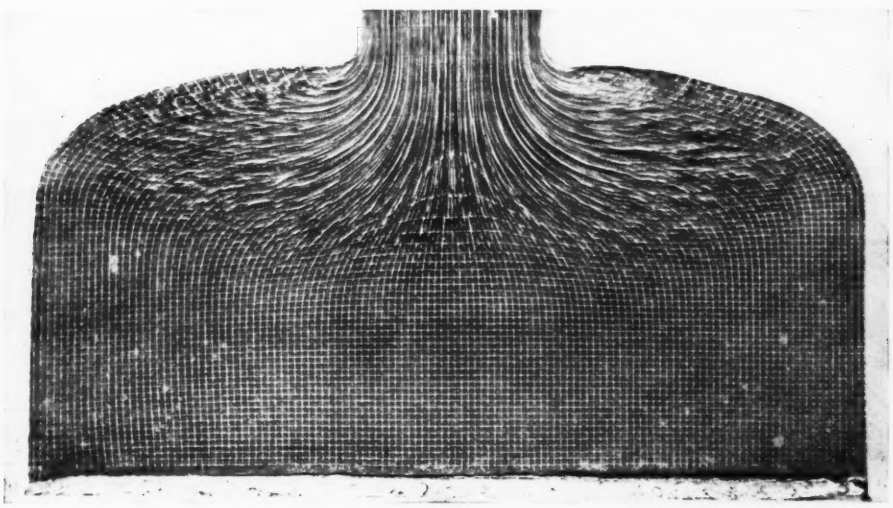
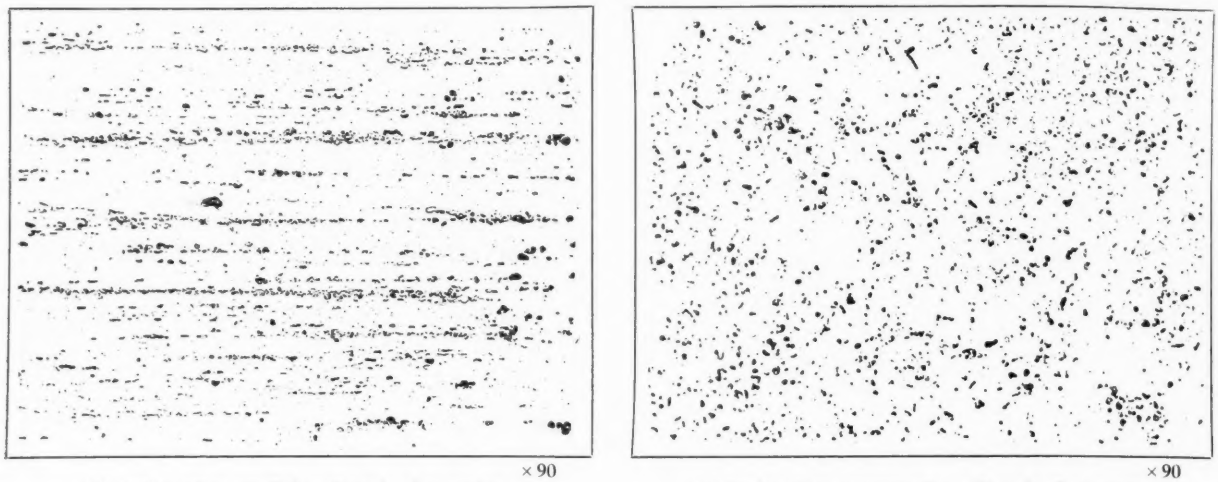


FIGURE 10. Metal flow in a lubricated billet during extrusion.



(*a*) Section taken parallel to the axis of extrusion. × 90

(*b*) Section taken transversely to the axis of extrusion. × 90

FIGURE 12. Structures typical of B.S. L.65WP extruded bar.

(2) *Rolled sheet or plate*

Sheet and plate are rolled from cast ingots of substantially rectangular section between substantially parallel rolls. In the first stages, rolling is carried out hot but in the later stages of sheet production, cold. The maximum sizes of rolled material which can be made depend on the size of ingot which can be cast and on the dimensions of the rolling mills available, keeping in mind that to achieve optimum " wrought " properties, a reduction of thickness during rolling of at least 90 per cent (or its equivalent) must be given.

The work imparted by rolling is much more uniform than in extrusion; it does not vary greatly from one end of the sheet to the other and, although it can vary to some extent through the thickness (the amount of work being greater at the surface than in the middle) (*See* Fig. 13), the variation is not sufficient to cause such a large difference in structure as that occurring in extrusions.

Ingots cast for rolling generally have their faces machined before rolling to ensure a smooth surface, since the " as cast " surface is rough and contains many imperfections which otherwise would persist through the rolling and impair the surface contour, corrosion resistance, properties and appearance of the final product.

Much of the sheet material used in aircraft has a thin coating of pure aluminium (99·7 per cent. aluminium) which protects the core gainst corrosion by virtue of its own intrinsically good corrosion resistance and its ability to protect by electrochemical means. This coating, or cladding, is applied during the rolling operation by rolling a sandwich consisting of the machined ingot between two thin plates of the pure aluminium (*See* Fig. 14). After the first pass through the rolling mill the " sandwich " sticks together and reduction of thickness takes place uniformly with further rolling. During these operations the oxide skins between the layers are broken down and the cladding becomes integral with the core.

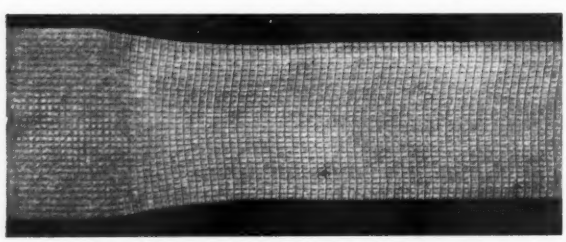


FIGURE 13. Metal flow in slab during rolling.

A problem which is divorced from the purely metallurgical aspects of manufacture concerns the production of sheet to meet flatness and dimensional tolerances. Regarding thickness, it can be appreciated that during rolling, the mill, including the rolls, deforms elastically, so that the finished thickness of sheet is greater than the initial roll gap. In addition, if the rolls are parallel to start with their deformation is such as to make the middle of the sheet thicker than the outer edges. The rolls are therefore usually made slightly convex, *i.e.* barrel shaped, to compensate for their elastic distortion. The matter is further complicated in that, during hot rolling and to a lesser extent cold rolling, there will be temperature gradients between the ends of the rolls and the middle, and temperature gradients will also be set up in both the rolls and the work material due to variations in the flow of lubricant. The temperature gradients in the rolls will cause non-uniform thermal expansion and thus alteration in camber. Variations in the lubrication will also affect the relation between rolling load and the amount of reduction. The rolling load will also be affected by the exact temperature of the material which is being rolled. Thus there are many reasons why there should be both variations of average gauge from a given mill setting and variation of gauge over the width of the sheet.

A further factor complicating the rolling process is as follows. If, during rolling sheet the reduction in thickness in the middle is greater than that at the outer

edges, then the middle will be too long compared with the outside and there will be a tendency for waves to form in the middle of the sheet. Conversely, sheet can be produced in which waves are at the outside and not in the middle. These faults are masked by subsequent distortion on heat treatment and are corrected to a large extent by subsequent flattening operations including stretching, but it must be remembered that once a dimensional incompatibility has arisen it is usually impossible to correct it completely, and some sign of it may persist in the final product.

It is of note that these problems can arise in spite of the use of 4-high rolling mills which have very great stiffness so that bending of the work rolls is small.

A further subject of importance is that of surface finish. Now the surface finish of sheet is dependent on a number of factors including roll finish, properties of lubricant and speed of rolling. A bright finish is the result of very smooth rolls, a lubricant of relatively low viscosity, and a limit on the speed of rolling. Under these circumstances the sheet is "burnished." These factors limit the economic production, in that rolls that are too smooth will present increased resistance to entry of the stock and thus limit the reduction of thickness per pass. As the speed of rolling increases, the thickness of the layer of oil between the rolls and the sheet increases, and the thicker layer of oil reduces the burnishing action of the rolls. Thus from the "production" point of view, it is an advantage to produce material with a slightly dull surface.

Although there is much greater uniformity of metal flow in the rolling process as compared with extrusion, a rolled product still has "directional" properties because it has been compressed heavily through its thickness and correspondingly extended lengthwise. This tends to impose a preferred orientation of the crystallographic structure which can cause a variation in the properties in test pieces taken at different angles to the rolling direction; it also tends to spread the inhomogeneities in the material to the form of elongated plates, which probably have little effect longitudinally or in the "long transverse" direction, but may have a large effect on the properties through the thickness direction.

(3) *Forgings*

Forging differs from the previous operations in that it has much greater possibilities of variation and can be used to produce much more complicated shapes. The problem of forging, apart from the obvious one of producing the right shape of product, is to ensure that the work applied to the metal is adequate in all parts and that the grain flow is in the best directions. This is not always easy, as is shown by Smith and Crowther[6] who illustrated the result of press forging between flat tools. They showed that, although apparently a uniform compression had taken place, only the middle had been heavily worked, but due to friction between stock and plattens a "dead" metal zone existed in the centre of each face where little or no work had been done.

A further source of problems in forgings is the "flash line," *i.e.* the plane of the parting faces of a pair

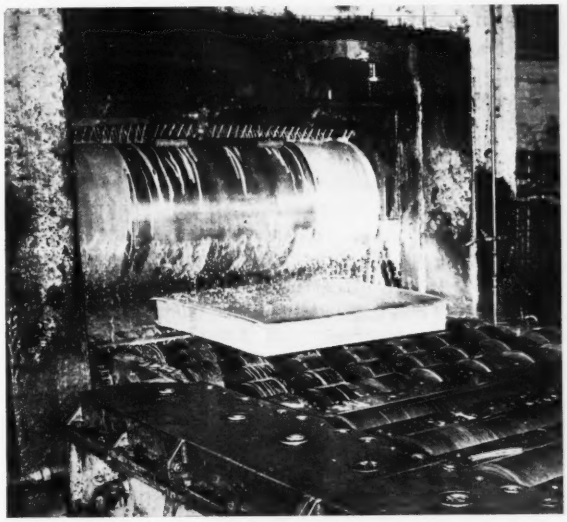


FIGURE 14. Rolling "clad" sheet.

of dies. It is virtually impossible when producing forgings to ensure that the dies are just exactly filled, so a small excess of metal is allowed for in the original forging billet. This metal is extruded or squeezed between the parting faces of the dies and as a result the grain structure, as in an extrusion, is highly directional along the lines of the metal flow. This results in poorer transverse properties across the flash line metal than in other parts of the forging. In addition to the directionality in the structure, any inhomogeneities present tend to be flattened and orientated along the lines of grain flow and in extreme cases this can result in the initiation of cracks at relatively low loads. The extrusion-like flow at the flash line also may cause overheating, which can result in cracks[7].

5. Heat Treatment

Before discussing the problems involved in the final heat treatment of strong alloys, it is as well to note its purpose. A number of aluminium alloys exist in which the alloying elements are present in appreciable proportion and form solid solutions with aluminium which are stable at room temperature. These alloys are not normally very strong. In the "strong alloy" the amount of alloying elements soluble at room temperature is small, but at high temperature a much greater amount is soluble. If the temperature of the alloy is raised so that the maximum possible amount is taken into solution and then is lowered slowly, the solute elements will be rejected from the solvent aluminium, but if the rate of cooling is very rapid the solute elements remain in solution.

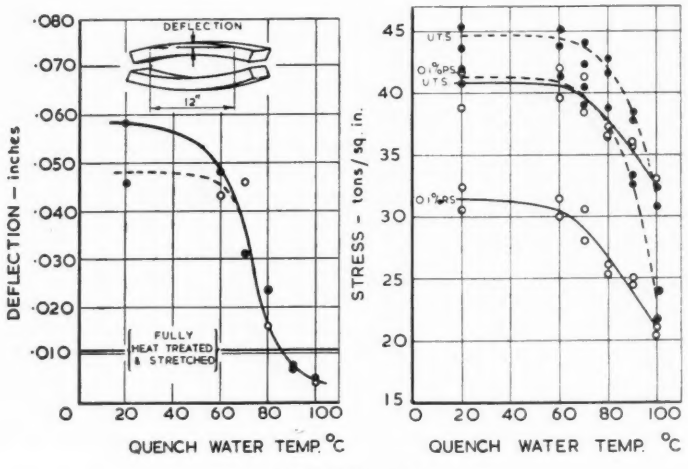
This solid solution is, however, unstable and the soluble elements tend to precipitate. The maximum strength of the alloy is achieved by allowing a controlled amount of precipitation. Depending on the alloy, high strength can be obtained after precipitation at room temperature, *i.e.* natural ageing, or after further heat

treatment at elevated temperature of the order of 120°C.—160°C., *i.e.* artificial ageing.

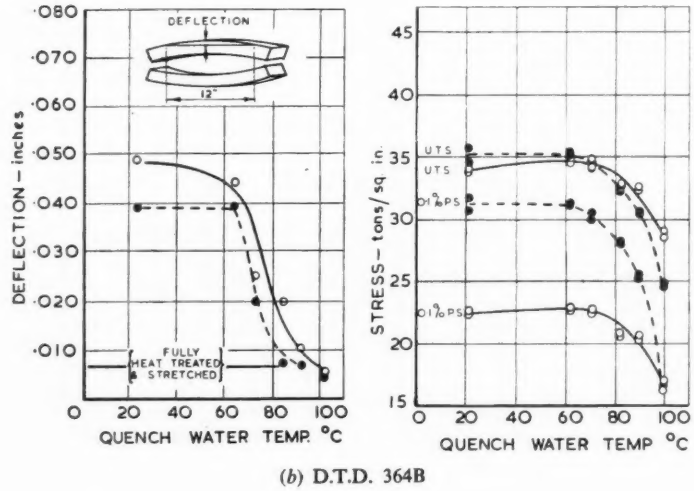
The solution treatment temperature is usually within the range 440°C.—530°C., the actual permissible range of temperature varying for each alloy. If the correct temperature is not reached, the quantity of alloying element dissolved is not sufficient to enable the material to achieve optimum properties after quenching. On the other hand, if the correct temperature is exceeded, low melting point material of near eutectic composition will form molten pools throughout the material. This overheating can have a detrimental effect on the properties, and if very severe will cause cracking during quenching or even at the heat treatment temperature. With modern furnace equipment, however, there is no great difficulty in raising the temperature of the material to the correct value and holding it there.

It is at this stage that small imperfections in the product, not noted at an earlier stage in production, may make themselves obvious. Discontinuities in the metal, due to oxide or other cause, may form a centre of concentration of hydrogen previously dissolved in the metal and formed by reaction between the alloy and the atmosphere in the furnace. This may cause "blisters" on or near the surface of the product. Blistered material is normally rejected by the producer but may be found by the user when he carries out heat treatment himself. By introducing fluoborates and other compounds into the furnace the incidence of blisters can be greatly reduced.

The chief problems due to heat treatment which face the aircraft manufacturer arise from the quenching operation. During quenching, heat is extracted rapidly but it is impossible to extract heat at the same rate from both the middle and the outside of a large mass of material such as thick plate, a heavy forging or a large extrusion. This difference in quenching rate can have some effect on the properties as will be discussed later. Other adverse effects of quenching are the distortion occurring during quenching and the high residual stresses which are induced. These stresses are caused by the plastic yielding undergone by the outer layers during the initial stages of cooling and the subsequent tendency for the middle region to contract away from the surface layers. The final stress distribution is a state of high triaxial tension in the middle and biaxial compression at the outside. The problem of heat treating without inducing high residual stresses or with reduced residual stresses has been dealt with by one of the authors in an earlier paper[8]. It will be enough at present to summarise the main conclusions in this paper and to make one or two additions.



(*a*) D.T.D. 363A



(*b*) D.T.D. 364B

○——— solution treated
●— — — fully heat treated

FIGURE 15. The effect of variation of the temperature of the quench water on the distortion after slitting and the properties of 3 in. square extruded section. (Ref. 23.)

Quenching stresses can be reduced by moderating the rate of cooling using oil, hot water or boiling water as quenching media (Fig. 15). The surface of the component being quenched, however, often plays an important part in governing the quenching rate. It has been stated recently[9] that the cooling rate of an anodised forging when quenched in boiling water is as fast as in an unprotected forging quenched in cold water; thus it would be expected that the residual stresses of an anodised component even though quenched in boiling water, would still be high. The slower cooling rates, although moderating the residual stresses, usually reduce the mechanical properties at the same time (Fig. 15). The extent of this reduction is partly dependent on the chemical composition (*e.g.* the properties of the chromium-free D.T.D. 683 material are not reduced as much as those of the alloy containing chromium[6]; there are, however, other ways in which the latter alloy is considered superior). A method of modifying quenching stresses not mentioned in the previous paper is the " thermal shock " treatment. This consists of inducing a temperature gradient, through the quenched component, approximately the reverse of the temperature gradient established during quenching. The required temperature gradient can be obtained by immersing the component for a short time in a bath of liquid held at high temperature[10], or by cooling the component to a low temperature and then restoring it to room temperature[11]. It is possible that a combination of these two treatments will give the most satisfactory results with the high strength alloys but it is most unlikely that, with regular shapes such as plate and extrusions, any of these methods will replace stretching as a method of reducing residual stresses. Stretching is discussed more fully in the next Section. The temperature gradients induced by the " thermal shock " treatment increase the compressive stresses in the outer layers until plastic deformation occurs; when the temperatures are subsequently equalised and the surface layers have contracted, both the core stresses and the stresses in the outer layers are reduced.

Quenching stresses can normally be reduced to some extent by subsequent artificial ageing treatments. The effects of these are limited and almost certainly seldom exceed 40 per cent. reduction of stress.

6. Subsequent Operations

Heat treatment and quenching generally result in considerable distortion of the product and it is necessary to correct this distortion to achieve the requisite straightness or flatness. Extrusions are usually corrected by stretching into the plastic range by amounts of the order of 1 per cent. or 2 per cent. Sheet is normally stretched as a final operation, but before stretching it is usually given a final pass with a very small reduction on the finish mill. The reason for this is as follows. Sheet that has distorted has contracted more in some parts than in others due to the cooling not being uniform during quenching. This results in some areas of the sheet being too large for compatibility with the surrounding material, and other areas being too small. This excess or deficiency of material is accompanied by a corresponding difference of gauge (from constant volume considerations). Thus the final rolling operation with correction of gauge will also correct the area incompatibility.

Stretching is fairly straightforward with extrusions except that extrusions are not uniform in strength over their full length and so are not given a uniform stretch, but with sheet, particularly thin sheet, it is more difficult. This is because the centre of a long sheet can contract laterally, whereas at the ends where it is gripped it cannot do so and the state of strain becomes non-uniform, which may lead to transverse waves being produced in the middle of the sheet.

The stretching operation is also the most satisfactory way of reducing to very low values residual stresses resulting from the heat treatment. The reason for this has been described in a previously mentioned paper[8], but a case of particular interest arises with thick plate, since here high quenching stresses are produced in two directions, whereas subsequent stretching is only in one, and the problem arises, how far can stretching in one direction reduce stresses in the plane at right angles to it. This problem has been solved by Alexander[12] who has shown that, while a given stretch will not reduce transverse stresses as much as longitudinal ones, the reduction will still be great (Fig. 16).

Dealing further with the reduction of residual stress by operations subsequent to heat treatment, the possibility of reduction of quenching stresses in plate by subsequent rolling is of some interest. It is known (Baldwin)[13] that a heavy rolling pass on initially stress-free material will induce residual compression stresses in the middle and residual tensile stresses at (or near) the surface—this is in the opposite direction from the

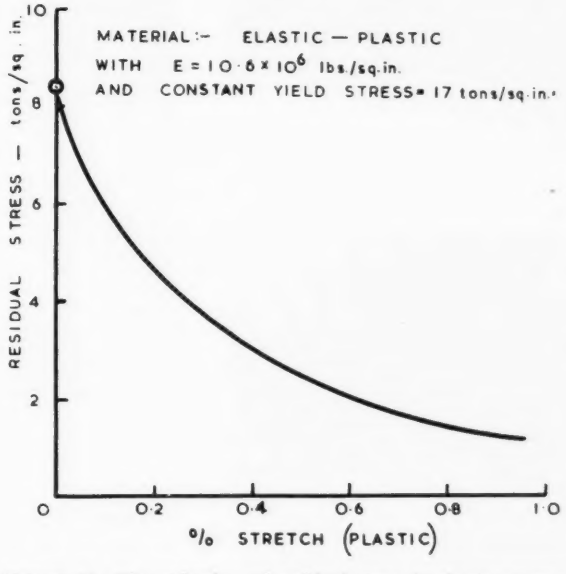


FIGURE 16. The reduction of residual stress in the transverse direction by stretching in the longitudinal direction. (Ref. 12.)

quenching stresses—while a slight pinch with small rollers will give a surface compression with a corresponding small tension in the centre. (Baldwin points out that this is an inference rather than a proven fact). This means that by suitable control of the final pinch it might be possible to diminish the quenching stresses by superimposing rolling stresses. The difficulty arises again that the effect of rolling is directional and the stresses due to rolling are not equal in both the longitudinal and transverse directions[14]. Unless the effects of rolling are more or less complementary to the effects of quenching, it is improbable that processes of this kind will ever replace the much more positive one of stretching.

7. Inspection

The basic reason for inspection procedures is to ensure that all the material that leaves the factory conforms to specification, for example with respect to chemical composition, mechanical properties and dimensions.

Until the past few years, if a material had faults which were not shown up by surface examination, tensile tests, or in certain circumstances etching of cross sections or by means of X-ray, there was no means of finding them.

Radiographic methods have been used for many years, but mainly in the inspection of castings and irregular shapes for comparatively gross discontinuities. An important change has been the development of ultrasonic techniques by which a beam of ultrasonic vibrations is projected into the metal and is reflected back by cracks or other discontinuities, observed generally by an indication on an oscilloscope. This is illustrated in Fig. 17. This shows cracks in the centre of a large extrusion and the indications obtained on the crack detector. In each case the central wave noted on the oscilloscope is the result of the reflection from the crack. This method of flaw detection is frequently used for inspection of important extrusions where size and shape permits its use and is also used in intermediate stages of production, for example of cast extrusion billets so that billets containing faults are rejected at this stage and before further work is done on them. The detection of large faults now presents no difficulty, but with faults of small sizes interpretation of the oscilloscope indication may be extremely difficult. At the present time the method used for the assessment of such small defects is to compare the amplitude of the echo indication obtained from the defect, with that received from the base of a flat-bottomed hole which has been drilled in a similar piece of material at an equivalent depth to the defect. Such readings are open to misinterpretation, but this still remains the best method available. Strictly speaking, the ultrasonic wave will be reflected by anything in the material of which the elastic constants are different from that of the surrounding metal, thus not only discontinuities such as cracks will

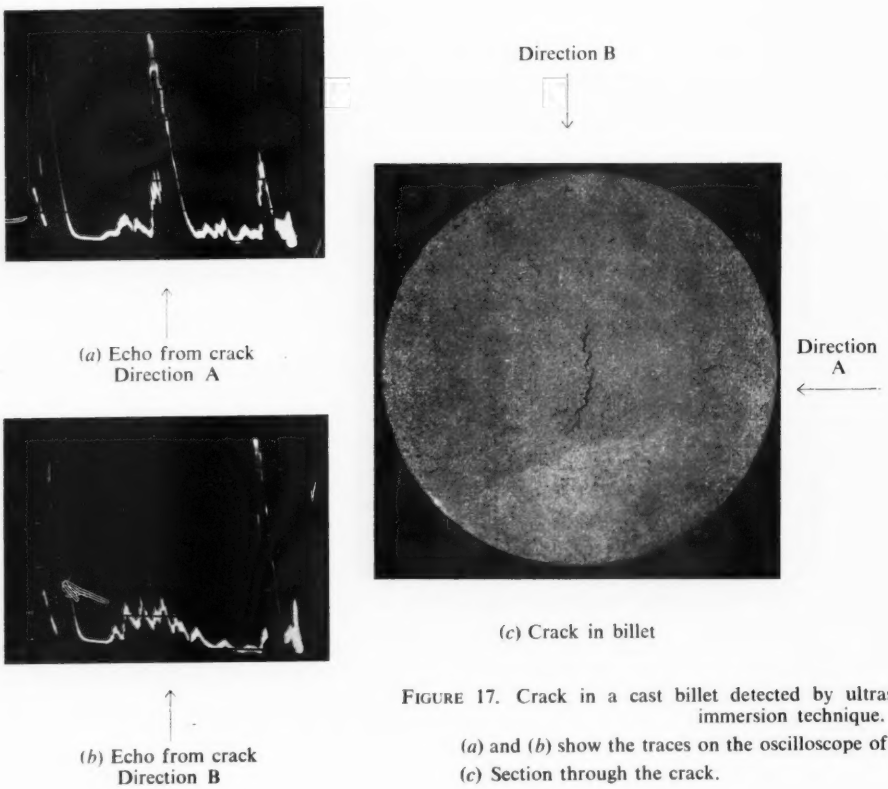


FIGURE 17. Crack in a cast billet detected by ultrasonic inspection using the water immersion technique.

(*a*) and (*b*) show the traces on the oscilloscope of the echoes from the crack.

(*c*) Section through the crack.

be indicated, but also metallic and intermetallic constituents, etc. This complicates the interpretation of the results but also opens up the possibility of wider application of these methods in the future.

Two recent developments are of interest. At present, ultrasonic flaw detection is mostly done using an oil film to couple the probes to the surface of the material under inspection. Although in the past this has proved to be a suitable method of coupling, it is no longer adequate for production inspection, since the size of defect which it is required to detect has become smaller and the speeds of inspection required have increased. Developments have, therefore, taken place in the United States[15], and are at present taking place in this country, on the use of immersion coupling techniques. In these techniques the materials to be inspected are immersed in a tank of liquid (usually water) and the coupling between the probe (or probes) is achieved by inserting the probe into the liquid. The intervening column of liquid forms a very efficient method of coupling and facilitates the automatic movement of the probe over a pre-set scanning pattern. It can be seen that this method of ultrasonic coupling opens up a very wide field for the development of automatic and high speed inspection techniques in production. Experimental apparatus is shown in Fig. 18.

The other development is the use of shearwave technique. This enables cracks to be detected in material of smaller section than is practicable with the present methods of longitudinal wave propagation.

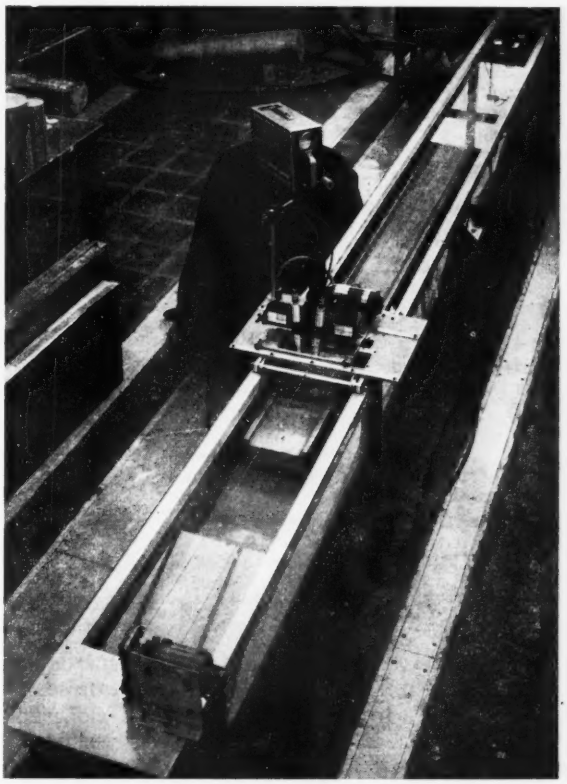


FIGURE 18. Experimental equipment for automatic ultrasonic inspection using the water immersion technique.

8. Discussion on the Effects of Production Variables on Mechanical Properties

8.1. TENSILE PROPERTIES

It is recognised by the appropriate specifications concerning the inspection and testing procedures that the properties of extrusions are not uniform over the whole section. As has already been mentioned, the properties of coarse grain outer band material are usually less than those of the finer grain core. However, in very large sections low properties may also be obtained in the middle of the section. This may be for a number of reasons; for example, there may be some degree of variation of composition across a section, the thickness of the section precludes a fully efficient chill in the middle during quenching, and the smaller amount of work done on the material in the middle of a large section may render the solution treatment itself much more sluggish. In Table II variation of chemical composition in a 6 in. square extrusion is shown. The variation in properties across the same extrusion is shown in Table III. These values are the results of longitudinal tests; the transverse properties will be dealt with later.

In an extrusion, apart from the extreme ends which have been cut off, there is a variation in properties from the front end to the back, as can be seen in Table IV where the tensile properties of the front end and back end of a large extrusion are compared. It may be advantageous to take into account this variation in properties along the length of an extrusion, by orienting the extrusion in a structure so that the maximum stresses are applied at the stronger end. It should be appreciated that the results in Table IV were obtained on an extrusion of the order of 30 sq. in. in cross-sectional area, smaller extrusions than this also tend to show a variation in properties, but the range is less.

In a large extrusion the transverse properties vary across the section in a way similar to the longitudinal properties. Results of transverse tests on the same sample as that which illustrated the variation in longitudinal test results are shown in Table V. The transverse properties are lower than the equivalent longitudinal ones, the most important difference being in the elongation, which can be very low in some cases.

The difference between the longitudinal and transverse properties is probably due to a number of factors including the preferred orientation, the alignment of intermetallic and non-metallic constituents parallel to the extrusion axis, the shape after mechanical working of porosity or any other discontinuity and the shape of the individual grains. This problem is worth discussing at some length particularly in relation to some work carried out by Dix[16] and by Van Horn[17]. The results of their work are shown in Fig. 19 where the properties of test pieces taken at various directions to the extrusion axis are plotted. The extrusion was 3 in. square bar.

TABLE II

VARIATION IN CHEMICAL COMPOSITION ACROSS A 6 IN. SQUARE EXTRUDED SECTION IN MATERIAL CONFORMING TO D.T.D. 683

Position of Sample	Cu%	Mg%	Si%	Fe%	Mn%	Cr%	Zn%	Ti%
Outside	0·69	2·67	0·21	0·34	0·23	0·13	6·27	0·05
	—	2·51	—	0·31	—	—	5·70	—
Middle	0·46	2·22	0·17	0·26	0·24	0·15	5·30	0·10
	—	2·36	—	0·32	—	—	5·65	—
Outside	—	2·75	—	0·33	—	—	6·22	—

TABLE III

VARIATION IN LONGITUDINAL TENSILE PROPERTIES ACROSS A 6 IN. SQUARE EXTRUDED SECTION IN MATERIAL CONFORMING TO D.T.D. 683

Position of test piece	*0·1 per cent. proof stress tons/sq. in.*	*Ultimate tensile stress tons/sq. in.*	*Elongation per cent. on* $4\sqrt{area}$
Outside	37·8	41·7	12
Middle	31·4	35·9	12
Outside	37·8	41·05	12½

TABLE IV

VARIATION IN LONGITUDINAL TENSILE PROPERTIES ALONG THE LENGTH OF A LARGE EXTRUSION IN MATERIAL CONFORMING TO D.T.D. 363A

Position of test piece	*0·1 per cent. proof stress tons/sq. in.*	*Ultimate tensile stress tons/sq. in.*	*Elongation per cent. on* $4\sqrt{area}$
Front end			
Outside	37·0	42·2	9
Middle	31·0	37·35	10
Back end			
Outside	39·15	43·5	7
Middle	32·9	38·5	10½

TABLE V

VARIATION IN TRANSVERSE TENSILE PROPERTIES ACROSS A 6 IN. SQUARE EXTRUDED SECTION IN MATERIAL CONFORMING TO D.T.D. 683

Position of test piece	*0·1 per cent. proof stress tons/sq. in.*	*Ultimate tensile stress tons/sq. in.*	*Elongation per cent. on* $4\sqrt{area}$
Outside	32·1	35·8	5
Middle	23·9	27·05	3
Outside	31·4	36·25	6½

There is marked dependence of the strength on the orientation of the test piece to the axis of extrusion—the minimum strength and the maximum elongation being obtained at 45° to the axis. This has been related to the preferred orientation of the crystal structure as follows. The grains in the extrusion are so orientated that, when the test piece is parallel to the extrusion direction, there are no ||| planes (the slip planes) on which the resolved shear stress is a maximum. As the angle of the axis of the test piece to the extrusion direction increases to 45° the degree of coincidence of the slip planes with the planes of maximum resolved shear stress increases—with consequent lowering of the yield strength; at angles greater than 45° the degree of coincidence decreases again and the yield strength, as expected, increases.

The ultimate tensile strength exhibits a relationship to the preferred orientation similar to that shown by the yield strength, but it is to be expected that it will not tie up as closely, since during deformation the original structural orientation will be considerably modified.

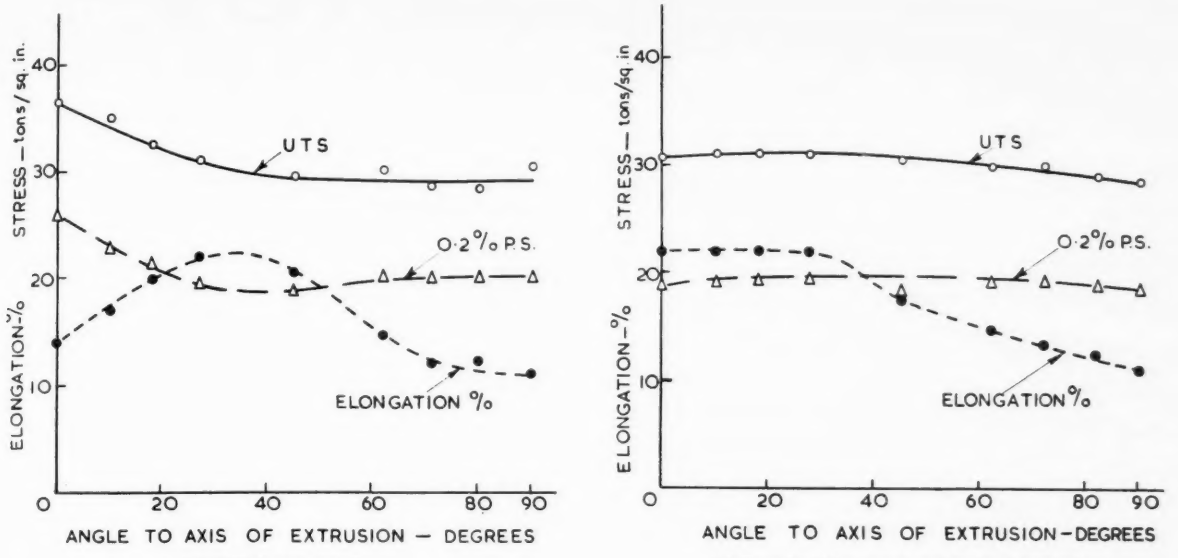
The elongation presents a still more complicated relationship since it is low both in the longitudinal direction and the transverse direction and increases to a maximum at some intermediate inclination. A second experiment on the same extrusion suggests the reason for this. A length of extrusion was stretched about 6 per cent and then re-heat treated. The original extruded texture was removed completely and replaced by a fully recrystallised structure which had little, if any, preferred orientation. The insoluble constituents and non-metallic particles were, however, still aligned in the direction of extrusion. The test results in Fig. 19 show that the strengths in all directions were very similar, as would be expected from a random distribution of orientations. The elongation, however, was still dependent on direction, being higher in the longitudinal direction than in the transverse direction. Obviously this is caused by some factor other than grain orientation and is probably due to the mechanical fibring of the insoluble material in the extrusion. It should be borne in mind that the more uniform properties of the fully recrystallised material were obtained by sacrificing part of the very high tensile properties which can be obtained in the longitudinal direction; it so happens with this particular alloy that, after the cold work and recrystallisation treatment, the tensile strength was below that required by specification.

Summarising these results, the variation of yield with orientation is related mainly to preferred orientation, while the variation of ductility is related to the linear or plate-like distribution of intermetallic and other constituents.

The variation in yield and in elongation with the direction of the test piece can be seen directly in Fig. 20 where the stress-strain curves for longitudinal and transverse test pieces are shown. Apart from the difference due to preferred orientation the curves are very similar until the fracture point of the transverse test piece. It can be seen that a material must be very brittle before the yield stress is affected by lack of ductility.

The tensile properties of high strength plate vary through the thickness, the middle region having slightly higher strength than that at the outside. This can be attributed to the greater degree of recrystallisation which occurs at the outside, due to the greater amount of working than is present in the middle of the plate.

Longitudinal properties of plate are similar or only slightly greater than those transverse to the rolling direction but in the same plane, but the properties



(*a*) Mill heat-treated. (*b*) Stretched 6 per cent and re-heat-treated.

FIGURE 19. The relation between the angle of the test piece to the axis of extrusion and the tensile properties.
(*a*) Highly preferred orientation of the crystal structure.
(*b*) Slightly preferred orientation of the crystal structure.
Alcoa 24S-T 3 in. square extruded section. (Ref. 16.)

through the thickness direction are lower, particularly the elongation.

The tensile properties of sheet are governed to some extent by the stretching operation; the increase in the longitudinal proof stress due to stretching is more pronounced than that in the transverse proof stress due to a form of Bauschinger effect. This cannot be avoided if sheet has to be stretched to enable close limits of flatness to be met. The yield and tensile strengths of clad sheet are lower than those of uncoated sheet by about 10 per cent., depending on the thickness of the coating, but the limit of proportionality is very much lower, being governed by the properties of the cladding. The primary limit of proportionality as it is sometimes called, is about 9 tons/in.^{2} (20,000 lb./in.^{2}), a stress at which presumably the cladding yields. Furthermore, with clad sheet, the stretching operation may be expected to put the cladding in compression, thus the limit of proportionality in compression may be less than in tension.

8.2. FATIGUE PROPERTIES

The fatigue properties of a material may be expected to react to certain production variables in much the same way as do the tensile properties, this variation of composition, amount of mechanical working and effectiveness of solution treatment may be expected to cause parallel variations in fatigue properties. There are, however, limits to the direct relationship between fatigue and tensile properties, set by the fact that fatigue failure depends much more on extremely localised conditions in the material than do tensile properties. Thus casting technique, since it determines

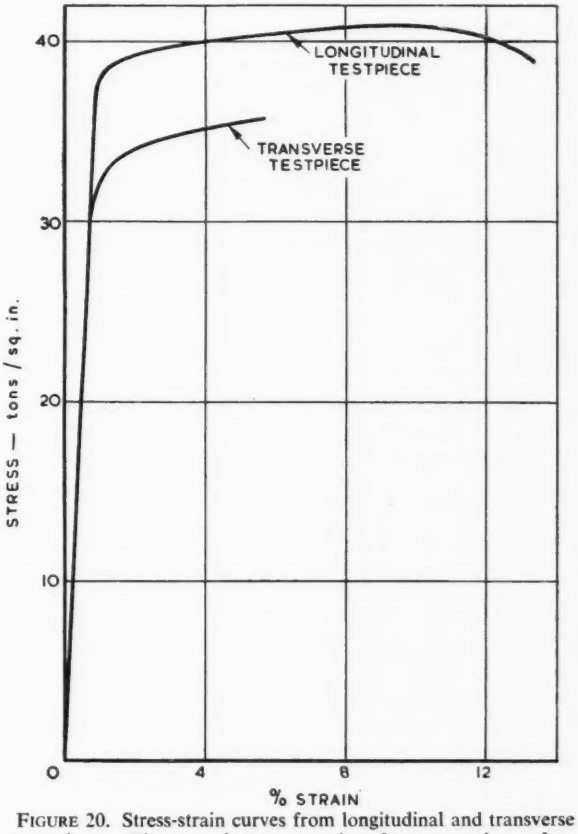


FIGURE 20. Stress-strain curves from longitudinal and transverse test pieces. The test pieces were taken from near the surface of a 6 in. square extruded section. D.T.D. 683.

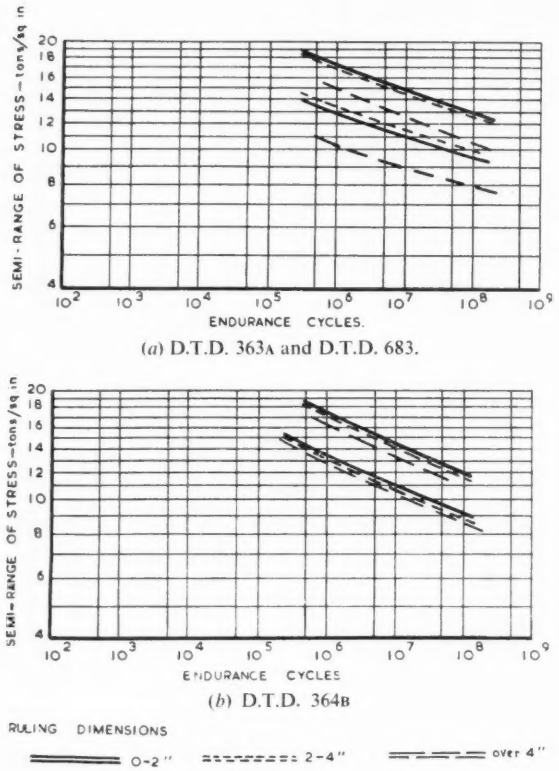


FIGURE 21. The ranges of fatigue test results that have been obtained on high strength aluminium alloy extrusions in rotating cantilever tests. The scatter bands embrace 90 per cent. of the test results. (Ref. 22.)

the constituent size and general structure of the final product, is likely to affect fatigue properties much more than it affects tensile properties. This is probably the reason for the wide variation of fatigue properties of the Al/Zn/Mg alloys, since with these alloys a wide range of cooling conditions may be necessary during casting which may result in great variation of metallographic structures.

It is not possible to show the effect of all production variables separately on fatigue properties, but Fig. 21 shows the combined effects of all of them together on rotating beam fatigue tests, for extrusions to D.T.D. 364 and the Al/Zn/Mg group of alloys respectively. The size effect in the latter case is clearly shown.

Fatigue tests taken from extrusions in the transverse direction are particularly interesting since the drop relative to the tests in the longitudinal direction is unexpectedly small. Templin[18] has stated that no difference exists between transverse and longitudinal properties. The present authors have found a difference of about 10 per cent. on samples of material of which the transverse elongation was quite low.

A factor affecting tensile properties much more than fatigue properties is grain size. The coarse grained outer band on extrusions can show tensile properties much lower than those of the adjacent fine grained material, whereas the fatigue properties show less change. There is in fact difference of opinion as to whether the fatigue properties show any effect at all. Templin[18] considers that they do not whereas others[19] consider the effects may be appreciable.

The fatigue properties of clad sheet[20] are of special interest since under normal laboratory tests they are shown to be appreciably lower than for similar but uncoated sheet (Fig. 22). It has been shown[20] that this is the case only under limited conditions of low mean stress. Where mean stresses are high, and also under conditions of high stress concentration there is little difference between the two materials. Under severe conditions of corrosion-fatigue, there is little doubt that the clad sheet will always show the higher properties.

8.3. STRESS CORROSION

Broadly speaking, the chief factor—after composition—in the production process which influences stress corrosion resistance is the heat treatment. This can be considered in two parts, the first is the effect of rate of quenching from the solution treatment temperature and the second is the effect of artificial ageing treatments on the stress corrosion resistance.

The stress corrosion resistances of the duralumin type alloys are impaired by decreasing the rate of quenching during heat treatment. The Al/Zn/Mg alloys are also affected in a similar way but they are not so sensitive as the duralumin alloys and can withstand appreciably less rigorous quenching conditions, without loss in stress corrosion resistance. The artificially aged duralumin type alloys (*i.e.* containing copper as the chief alloying element) have less resistance to stress corrosion than their naturally aged counterparts. On the other hand the Al/Zn/Mg alloys after artificial ageing have much better resistance than the same alloys which have been naturally aged.

9. Bending and Forming

The two questions on bending or forming usually put to manufacturers are—" How far is it possible to form a certain alloy without fracture during forming? " and " Is it in a suitable state for use after forming? " *i.e.* " Can it be done? " and " Is it safe? " Of these, the second is the more important, but some comments on the first may be useful.

The limit of bending of a narrow beam is related more to the reduction of area obtained in a tensile test than to the elongation measured over a finite gauge length[21]. This means that strictly from the point of view of the limit of bending, it is possible to bend fully heat-treated material nearly as far as solution-treated material, with suitable control of the bending operation, although the elongation of the latter may be considerably greater than that of the former.

The extent to which plates or wide beams can be bent also appears to be related to the reduction of area, but the relation is much more complicated since fracture occurs under biaxial stress in which the second principal stress is approximately half the maximum principal

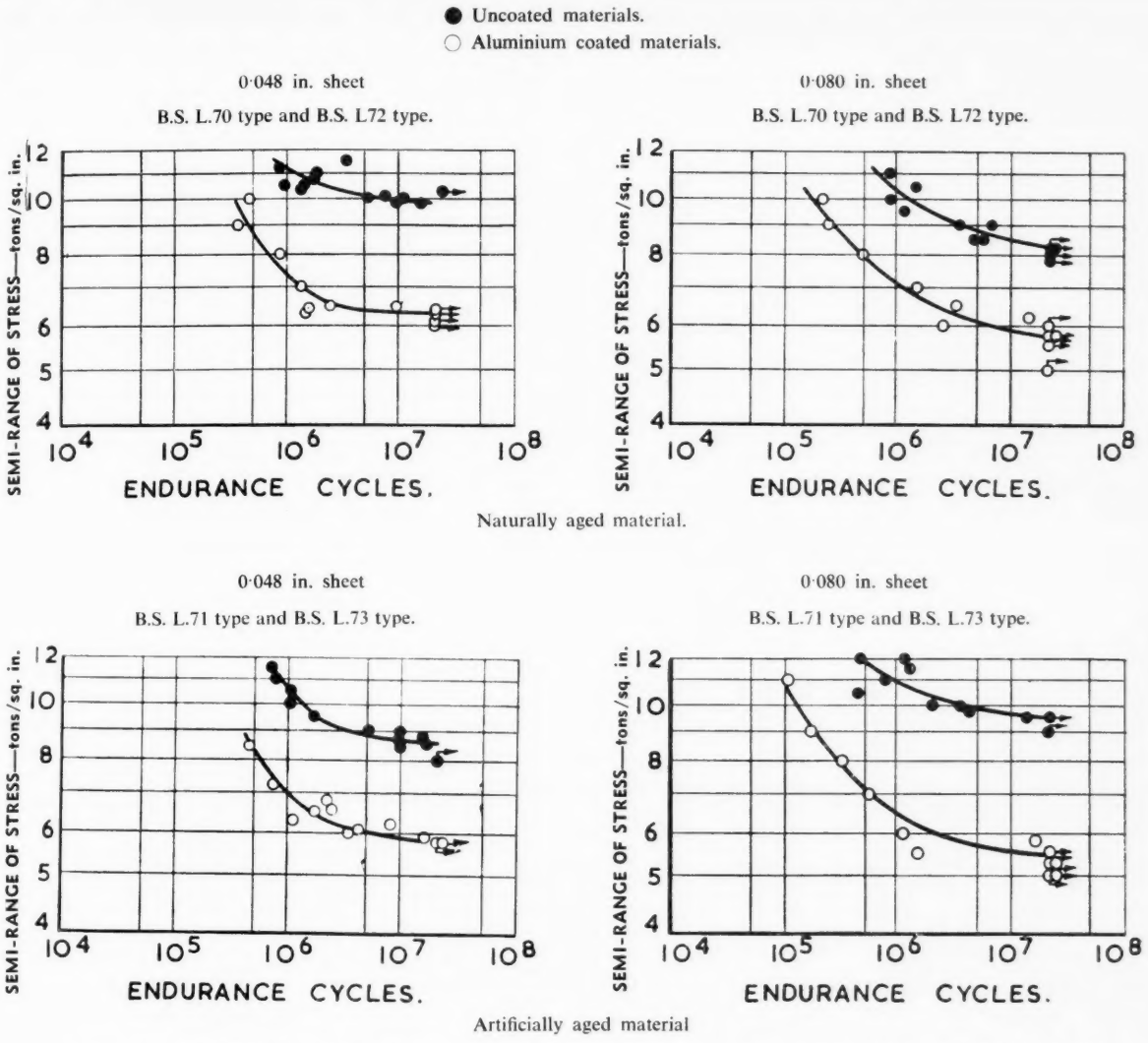

● Uncoated materials.
○ Aluminium coated materials.
0·048 in. sheet
B.S. L.70 type and B.S. L.72 type.
0·080 in. sheet
B.S. L.70 type and B.S. L.72 type.
SEMI-RANGE OF STRESS—tons/sq. in.
ENDURANCE CYCLES.
Naturally aged material.
0·048 in. sheet
B.S. L.71 type and B.S. L.73 type.
0·080 in. sheet
B.S. L.71 type and B.S. L.73 type.
SEMI-RANGE OF STRESS—tons/sq. in.
ENDURANCE CYCLES.
Artificially aged material

FIGURE 22. The effect of cladding on the fatigue behaviour (reversed flexure) of duralumin-type material. (Ref. 20.)

TABLE VI

MAXIMUM DIAMETER OF CIRCLE WHICH CAN BE DRAWN THROUGH A DIE USING A 2 IN. DIAMETER FLAT BOTTOMED PUNCH

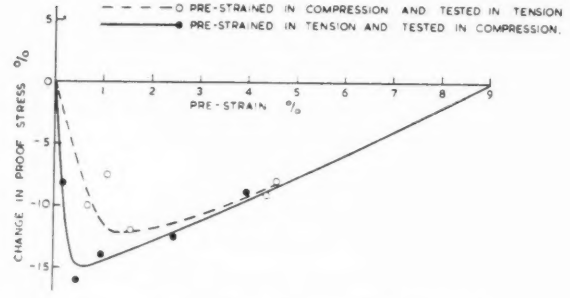
Material—H.S. 20

Condition	0·1 *per cent. proof stress tons/sq. in.*	*Ultimate tensile stress tons/sq. in.*	*Elongation per cent. on 2 in.*	*Diameter of circle*
Annealed	3½	8	26	4⅛
Immediately after quenching	5	12	25	4⅛
Naturally aged several days	10	14	20	4⅛
Fully heat-treated	17½	21	13	4⅛

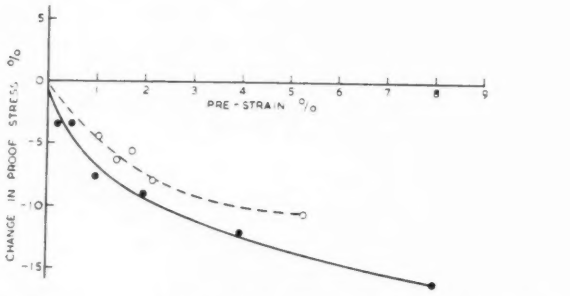
stress. Under these conditions the effective ductility is related not only to the reduction of area but to the work hardening characteristics of the material in that, if the material work-hardens very little (*e.g.* an artificially aged alloy), the effective ductility is less than if it work-hardens a great deal.

In operations which are mainly forming by stretching, the relative values of the alloys are dependent on the general elongation rather than the reduction of area, thus the amount which can be carried out on the naturally aged material is much greater than in the artificially aged condition.

One other case is of importance—the limits to which the alloys may be deep drawn. Here the deformation is almost entirely by compression and some materials even with a low tensile elongation may deform very greatly in compression without fracture. When a


PRE-STRAINED IN COMPRESSION AND TESTED IN TENSION
PRE-STRAINED IN TENSION AND TESTED IN COMPRESSION.
CHANGE IN PROOF STRESS %
PRE-STRAIN %

(*a*) Pre-strained in the fully heat-treated condition.



(*b*) Pre-strained after ageing naturally for a long time. Tested in the fully heat-treated condition.

FIGURE 23. The effect of unidirectional cold work on the tensile and compressive properties of a sample of D.T.D. 363A extruded section. The diagram illustrates the Bauschinger effect.

material fails in a deep drawing operation such as the production of flat-bottomed cups, by tearing of the base, it is because the tensile strength of the wall of the partially formed cup is not great enough to withstand the load required to complete the drawing operation. Thus if failure is not obtained under compression, the most important characteristic is a high ultimate tensile stress compared with the compressive strength at high degrees of strain. Table VI[21] shows the maximum diameter of the circle which can be drawn through a die of a given size in a variety of aluminium alloys; it can be seen that although the tensile ductilities vary greatly, the diameter of the circle remains the same.

The second question is "How far can one form material without damaging it?" In general, cold forming results in hardening of the material coupled with reduction in ductility. As long as sufficient residual ductility is allowed to remain to cope with the redistribution of stress round holes, etc., there seems to be no reason to limit forming operations. There are, however, certain effects of forming which must be emphasised. One of these arises from the Bauschinger effect. This effect can be described as follows. If material is stretched, the compression strength at small plastic strains may be lowered and conversely after compressive straining the tensile proof strength may be lowered. Thus if a beam is bent, material from the compressed side of the beam may show a lower proof stress in tension than the unformed material. Fig. 23 shows examples of this. This Bauschinger effect accounts for the fact that, in some materials which are

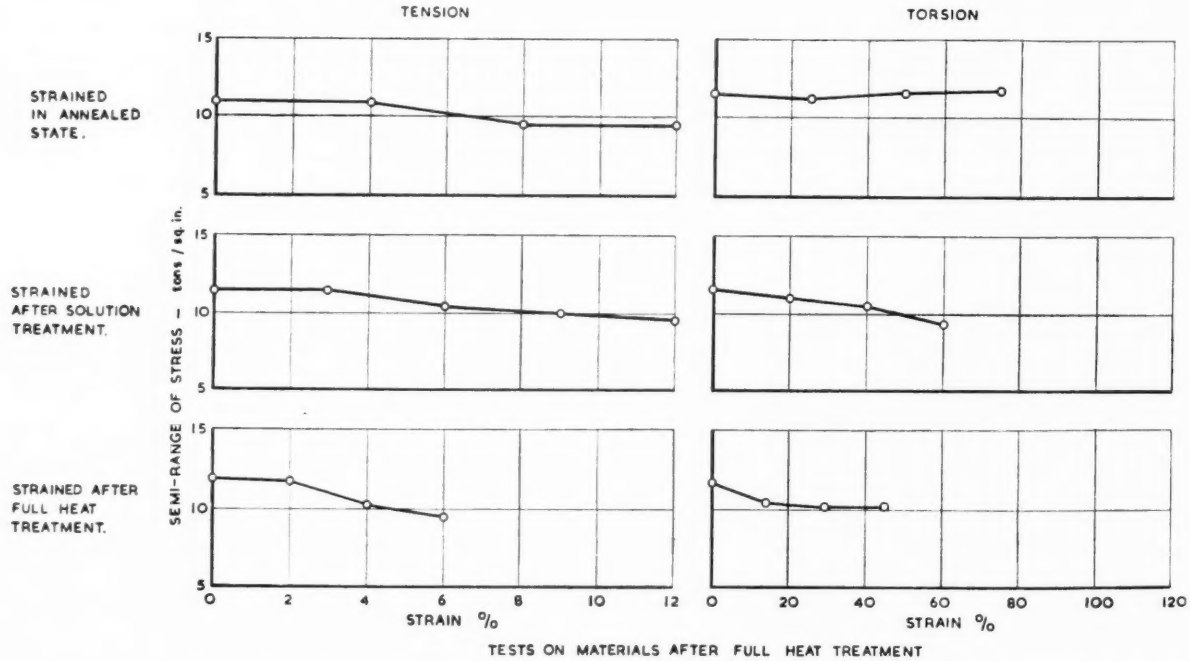


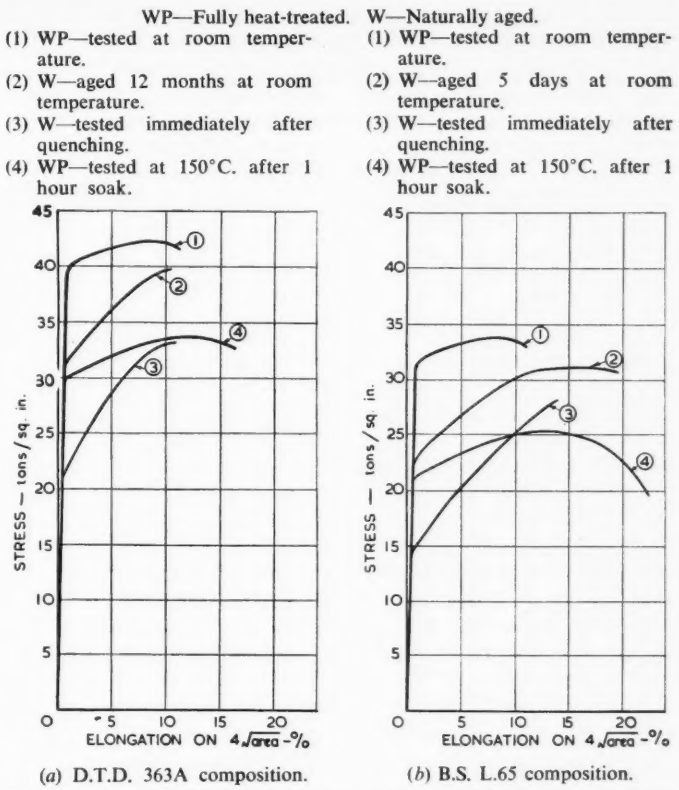
FIGURE 24. The effect of cold work (by tension or torsion) at various stages of heat treatment on the fatigue strength (50 million cycles) of D.T.D. 364B alloy. Rotating cantilever fatigue tests. Tested in the fully heat-treated condition. (Ref. 24.)

stretched after heat treatment, compression properties are not quite as good as those in tension.

Some effects of cold forming on fatigue are shown in Fig. 24 which concerns a material conforming to D.T.D. 364, forming having been carried out in the annealed, solution-treated and fully heat-treated states[24]. This shows that a reduction of fatigue strength may occur under certain circumstances but that, even when plastic deformation due to forming is high, the effect on fatigue is not great.

A further effect of forming operations is the introduction of residual stress systems. Residual stresses due to forming may have values only limited by the yield stress of the material[8] and these stresses may improve or damage performance (particularly fatigue and stress corrosion) according to their sense. If the sense cannot be controlled, they should be kept as low as possible. To accomplish this, forming should be carried out (except in special cases) when the material is solution-treated and as soon after quenching as possible, or even before solution treatment. The latter method has the disadvantage that complete heat treatment is needed after forming; this causes distortion which must be corrected by further forming and so in many cases the final product has little advantage over that formed after solution treatment. When material is formed after solution treatment and before artificial ageing, it has the advantage that the residual stresses are related to the relatively low properties of the material immediately after quenching and are further reduced by the artificial ageing. This procedure, however, has the disadvantage from the point of view of the aircraft manufacturers, that they must operate artificial ageing furnaces themselves, or make arrangements with the material producer to collect, age and return the formed parts. Of recent years there have been, therefore, attempts to form after full heat treatment but at elevated temperatures. The maximum temperature at which this can be carried out is about the artificial ageing temperature of the material, otherwise a loss of properties is obtained at room temperature.

Figure 25 shows stress/strain curves for fully heat-treated B.S. L.65 and D.T.D. 363A materials tested at room temperature and at 150°C. The yield stresses are considerably reduced by testing at 150°C but, as is also shown in Fig. 25, they are not reduced to the values obtained on material which had been tested at room temperature after quenching from the solution treatment temperature. This means that the residual stresses, induced by forming immediately after quenching, will be lower than those induced by forming fully heat-treated material at 150°C. Furthermore, as already mentioned, the residual stresses induced by forming in the solution-treated condition will be reduced by the



(*a*) D.T.D. 363A composition. (*b*) B.S. L.65 composition.

FIGURE 25. Stress-strain curves to fracture for two high strength aluminium alloys in various conditions of heat treatment. 1 in. diameter extruded bar. (Ref. 23.)

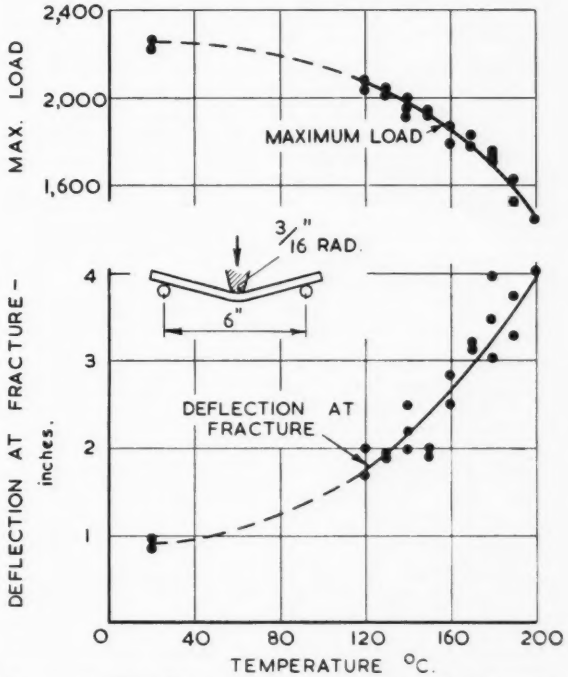


FIGURE 26. The effect of temperature on the bending characteristics of D.T.D. 363A extruded bar of ½ in. square section. (Ref. 23.)

subsequent artificial ageing treatment. Thus if only residual stresses were to be considered, warm bending fully heat-treated material would have no advantage over bending freshly quenched material cold. On the other hand, warm bending solution-treated material may give appreciable advantages. The chief advantage of "warm" bending is that increased ductility can be obtained[23]. This is shown in Fig. 26 for D.T.D. 363 material. It shows that the deflection at fracture is about twice as great at 150°C as it is at room temperature.

10. Conclusion

In this paper an attempt has been made to survey the problems of production and use of aluminium alloys as they affect the user. This is to say that many of the problems arising in manufacture which result in rejection of material before it reaches the user have been ignored or only briefly mentioned as being of little interest to the aircraft manufacturer. Similarly only the heat-treated alloys have been considered in detail since it is with the strong alloys that aircraft manufacturers are chiefly concerned. The authors have concentrated on those factors which govern the behaviour of material after it has been received by the aircraft manufacturer. If this paper has given him a clearer picture of the material with which he has to deal, it will have served its purpose.

ACKNOWLEDGMENTS

The authors wish to convey their thanks to numerous colleagues in Northern Aluminium Company Ltd. and Aluminium Laboratories Limited for a great deal of very generous help and advice in the preparation of this paper.

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DISCUSSION

R. BOORMAN (Chief Structural Engineer, Short Brothers and Harland Ltd., *Fellow*): This being their sole parent body lecture this season, he was reminded that, from time to time, they as "outposts of Empire," as it were, in Belfast, were tempted to grumble that they did not have available to them the full facilities of the Royal Aeronautical Society. They had even been known to petition, as a Branch, to the parent body for some reduction in membership fee as was given to other members serving abroad!

Not that they were actually abroad but that strip of water that the President-elect had crossed must have made him realise that they were at a disadvantage.

Their disappointment arising from the treatment by the parent body was, however, to some extent, mollified on such occasions as that evening, when they were pleased to welcome the President-elect together with Dr. Ballantyne and other members of the parent body; particularly when they brought with them such experts in their field as Mr. Forrest and Mr. Gunn.

He had found the paper extremely interesting, and was sure that most of the members had also, particularly those who had not had the opportunity of visiting a light alloy plant. He would not forget the first occasion on which he saw continuous casting being done. The pouring of the molten metal into such a narrow casting ring, the bottom of which was slowly dropped away into space, leaving behind the growing solid ingot savoured of sheer magic, and it was not until he had had a second peep over the rim of the mould that he was convinced that the whole thing was not trickery. He had not appreciated, however, until he read this paper, the exacting care which had to be taken with such things as preserving, unbroken, the oxide skin and the maintaining of exact pouring rates to ensure this requirement. In fact, the many requirements on both pouring and cooling rates to mitigate against the formation of porosity cracks and coarse structures were so conflicting that he now had a more healthy respect for the light alloy manufacturers than he was afraid he had had in the past.

When they had had troubles with the material with which they were supplied perhaps they had been too prone to blame the manufacturers and, in relation to these troubles, he was pleased to see the developments taking place in ultrasonic flaw detection, for he was sure that an intelligent application of such methods of inspection should provide the aircraft fabricator with a sounder material, less prone to flaws and cracks.

Previously, on many occasions, such flaws had not been discovered until after very expensive machining operations had been carried out, and spars and forgings had very often had to be scrapped. Presumably there had been some redress from the suppliers, but he doubted very much whether that had always covered the money and time lost in the part fabrication or the shipment of material. He only hoped, however, that the introduction of ultrasonic flaw detection would not increase the price of the material nor delay their receiving it. Perhaps the lecturers would care to give some views of this aspect.

He knew that his colleague, Mr. Conway, was not entirely with him in welcoming this method of inspection, and was, he believed, rather sceptical about its efficacy, so perhaps Mr. Conway would like to raise his arguments.

He was interested, too, in the graphs showing the wide scatter on the fatigue properties of the aluminium zinc magnesium alloys compared with duralumin type 364, and allying this undesirable characteristic with all the other troubles one heard about these days with the aluminium zinc magnesium alloys, one wondered why they continued to use them. Certainly on civil aircraft, with the necessity to maintain a long life, one was tempted to turn to the more docile duralumin type alloy, but even on Service aircraft where perhaps long life was not so essential, one heard of so many troubles arising from cracking and high internal stresses and stress corrosion that personally he was beginning to wonder why they did not discontinue to use them entirely and cancel the specifications. Perhaps the lecturers would like to remind him what the advantages were in view of all their disadvantages, because frankly he was fast losing sight of them.

What of the future? Were they ever going to get tapered sheet in production quantities in this country? The U.S.A. had it, and Germany could supply it. Perhaps the reason for the latter case was because they were defeated in the last war and therefore could not sit back on their "laurels" as we seemed to have done.

What too, of thick rolled stretched slab for integral construction and also integrally stiffened sheet extrusion? It was as long as four years ago that at Short Brothers they designed and built an integrally stiffened box, and the slab that they procured for this exercise was some 10 ft. long by 2 ft. wide by 2 in. thick, and they had great difficulty in obtaining it then. Now, some four years afterwards, so great had been the progress that the largest piece they could get was still 10 ft. long by 2 ft. wide by 2 in. thick!! What was going to be done about it?

He was greatly impressed when he read the paper by the many conflicting requirements necessary to produce sound material. For instance, on the one hand, casting and cooling rates must not be too fast so as to produce internal stresses and cracks, while on the other hand not so slow as to produce coarse grained structures. It seemed that whichever way the light alloy manufacturers turned, they were in for trouble.

K. L. C. LEGG (Chief Structural Development Engineer, *Associate Fellow*): He would like to endorse Mr. Boorman's remarks about the lecture. He also found it most interesting and revealing.

He was very interested to hear that stretching might have an appreciable reduction on transverse residual stresses and in view of the limited stretch press capacity in this country, he wondered whether this process would work effectively in reverse; that was, in order to stress-relieve large plates, for which they had not got the stretch press capacity at present, to apply successive compressions in the short transverse direction using a large forging press, at least, such of the large forging presses as there were in this country.

A recent development which was receiving a great deal of attention in the Aircraft Industry was chemical etching. This was a process which involved the immersion of aluminium alloys in a fairly strong solution of caustic soda; such a vigorous treatment naturally shocked the average aircraft engineer, but according to all preliminary reports it had no severe adverse effects on the material. He wondered whether the lecturers would care to comment on this, particularly with regard to stress corrosion and fatigue.

Mr. Boorman had raised the point of zinc bearing alloys being inferior in fatigue to the copper bearing

alloys; he believed that was particularly so where stress raisers were present, in a normal aircraft joint for instance. Taking this point a little farther it was interesting to try to analyse what advantages zinc bearing alloys offered to the aircraft engineer today. First of all current practice on civil aircraft and transports, and possibly on other types of civil aircraft, was to limit the design tensile strength solely on fatigue considerations so that they were not taking full advantage of the higher ultimate strength of these zinc alloys. Secondly, in compression, they were now tending to work in a very high stress region around the 0·05 per cent. proof stress and recent research work at the R.A.E. on D.T.D. 646 and 687, these being respectively the copper and zinc bearing alloys, had shown that the more favourable stress-strain curve in this region was derived from the copper bearing alloys where compressive stability was the criterion. In other words they had a more favourable f/E_t value. Furthermore, zinc bearing alloys had a bad tendency to shatter. They had had many examples of this at Shorts in testing both sheet material and large forgings. The failure was virtually an explosion and the material shattered. This shattering tendency was much less violent with the copper bearing alloys. Also there was a far greater distortion problem during machining and heat treatment in the zinc bearing alloys than the copper bearing ones. Finally, for temperature applications it was well known that the copper bearing alloys were superior to the zinc bearing alloys with regard to strength and stiffness at elevated temperatures. There would seem, therefore, enough evidence there to limit the use of the zinc bearing alloys to a few minor applications.

Having mentioned elevated temperatures he should say that the next generation of aircraft was undoubtedly going to be well and truly supersonic and one wondered what the light alloy industry were going to do to keep in business—assuming, of course, that they ever made any money out of the Aircraft Industry. According to most people's calculations light alloys, as a primary structural material, were unsuitable for speeds greater than a Mach number of 1·5 to 2·0 due to kinetic heating problems. One interesting development was the powder metallurgy technique which was typified by Hiduminium 100 which, although having fairly low room temperature properties, had good specific properties at elevated temperatures up to about 400°C. or so, which was equivalent perhaps to a Mach number of 3 or 3·5. Perhaps the lecturers would comment on these observations.

E. T. JONES (*Chairman*): Mr. Boorman, he thought, asked when they were going to have tapered sheets. He would ask when they were going to make provision for them to have tapered extrusions? He had asked a metallurgist that some time ago and had been told that it would mean an entirely new extrusion press. He could not see why there could not be a die which varied as the material went through it.

H. G. CONWAY (Director and Chief Engineer, Short Brothers and Harland Ltd., *Fellow*): His own experience with ultra-sonic inspection was that it was a difficult technique to apply in many cases. In the case of welded steel sheets some tests showed that as many faults were found that were not there as faults that were. Unless the inspector using the equipment became highly trained and experienced, difficulties would undoubtedly ensue. As Mr. Forrest had said, it was a matter of interpretation. It would probably be a mistake to specify this type of inspection too widely at this time until firms had acquired more experience. On the other hand one of the material firms to whom they had referred this matter recently, wrote back and said that their objection was that it would make deliveries more difficult. The implication was that they had been supplying them with material with faults in it. This might be true but the ordinary engineer would be surprised because he thought that his material was perfect.

On the question of tapered sheets, he did not agree that it was as easy as Mr. Forrest suggested. To produce tapered sheets process control equipment on the rolls was needed—means of varying a separation of the rolls as the sheet passed through it. To his knowledge nobody had got that in this country. It was not much use talking to the sales department until the factory was properly equipped. They were being offered tapered sheet produced in Germany from equipment that was already available. British industry should provide the factory and then they would start using the material.

Could the lecturers indicate what stress corrosion was?

C. P. T. LIPSCOMB (Director, Short Brothers and Harland, *Fellow*): He would like to emphasise more what Mr. Boorman and Mr. Legg had said about those two serious problems, cracking and fatigue.

There was no doubt that civil operators were extremely worried about these problems, and although he did not propose to enlarge on the troubles that they had experienced, it was certain that they were expecting some drastic action to be taken in the near future.

Whether the designers could be blamed for asking for too high a ratio between the proof and ultimate stresses, or whether they were wrong in using fully heat-treated material he did not know.

There was no question that an exhaustive investigation must be made, as it might well be necessary in the future to use a lower ratio of proof to ultimate stress in order to give an opportunity of redistributing the stress in components and lowering the concentrations. He felt that some of their troubles were, undoubtedly, due to designers insisting on these high proof stresses and also probably to the large forgings now demanded, which often suffered from a lack of homogeneity.

Could the manufacturers hold out any hope that designers could go on using these high proof stresses and still retain a long fatigue life? This question of fatigue was a serious, as well as a costly, one to the civil operators and could not lightly be dismissed because of the possible catastrophic results due to a failure.

The whole subject, therefore, needed a serious investigation and possible action.

W. H. HAMBROOK (Technical Manager, Short Brothers, *Fellow*): He was impressed with the lecturers' figures illustrating the flow of metal during the extruding process, which supported his view that the method of producing extrusions was not quite right. To take a metal and squeeze it past a sharp cornered orifice did not seem to savour of normal engineering technique. By reference to Fig. 7 it seemed to him to be abundantly clear that the metal flow indicated precisely the path which it really ought to follow. Was there any reason, therefore, why the internal shape of the extrusion die should not be copied from the clearly defined contour lines shown by the diagram? He imagined there might be strong reasons against the suggestion because of the pressures involved, and also perhaps due to excessive friction forces. He thought that the lecturer would probably agree with his point, since by implication the principle appeared to have been partially followed, although not necessarily for the same reason, in the design of the die for the extrusion used to produce the specimen shown in Fig. 10.

MR. E. T. JONES (*Chairman*): It was always a good thing to stop any meeting or lecture when it was still in the interesting stage and he thought therefore that he should draw this lecture to a close. The Society were most grateful for the work of the Branches and he would like Mr. Keith-Lucas to wind up the evening. It was a fine lecture and he wished to congratulate the lecturers.

MR. KEITH-LUCAS: He wished to thank the Chairman for giving him this opportunity and on behalf of the Branch would like to thank the lecturers, the President-elect and all their visitors from England. It had been a most interesting evening and they were honoured indeed to have been chosen again to be hosts for one of the parent body lectures.

MR. FORREST'S REPLY

MR. BOORMAN: First, with reference to ultrasonic testing. That it would produce improvement in the material, he thought there was no doubt at all. Already it meant that cast billets with cracks in them were rejected before they ever got as far as the extrusion press and, presumably, that many extrusions were rejected before machining which previously would only have been rejected after machining. Large cracks could easily be detected. The difficulty arose when the defects causing indication on the oscilloscope screen were very small, because they did not then know what the indication really meant. Sooner or later they had got to draw an arbitrary line and say that they would reject anything which gave an indication above a certain size. It must be remembered that wherever the line was drawn, material which had been inspected by these methods was certainly better, on the average, than material produced earlier. Mr. Boorman mentioned the effect of such inspection on price and delivery. If the inspection level were drawn so that the rejection percentage was too great, it would push the price up and push back the delivery and he thought one wanted to be sure that such rejection was justified before setting the inspection level too close.

Regarding fatigue and the aluminium zinc magnesium alloy, Mr. Boorman raised the question of why they used these alloys. Well, he really thought the Aircraft Industry ought to tell them that. He thought it was because they had high static tensile and compressive properties and that these properties were of value. Considering fatigue alone, personally, he would like to see more use, not only of the fully heat-treated Al/Cu alloys, but of the naturally aged versions—and he knew Mr. Gunn would agree—because of the resultant lower proof stresses allowing relief of stress at points of extremely high stress concentration, and also of high residual stresses.

The next question concerned the production of tapered sheet and thick rolled and stretched slab. Regarding tapered sheet, they would probably get a more complete answer from their normal contacts with the aluminium industry than he could give at present. Briefly, he thought they would probably get tapered sheet if the urgency of the requirement were demonstrated to be sufficiently great.

The main difficulty in producing thick rolled stretched slab was the limited stretching capacity at present in this country, but this position would shortly be improved. Additional stretching facilities were being installed which would enable plate of 200 sq. in. cross-sectional area to be stretched. These facilities should be available during the next year.

MR. LEGG: Mr. Legg suggested that residual stresses in thick plate could be reduced by compressing in the short transverse direction. He had had no experience of the effect of forging which Mr. Legg suggested, but the result might well be similar to that of rolling as he had described. The difficulty with rolling for this purpose was that the reduction value to give least stress was very small (about $\frac{1}{2}$ per cent) and very critical. If this value were appreciably exceeded, tensile stresses were induced in the surface and the final condition was as bad as the original one. A similar objection probably applied to methods of reducing residual stresses by "reversing the quench," *i.e.* by giving a short treatment at a high temperature. These were, therefore, difficult processes to use commercially. Stretching, on the other hand, was not critical in this way, since with increasing strain new residual stresses were not induced.

They had not done any work on chemical etching at Laboratories, but he thought that the etching might reduce the fatigue properties as compared with polished specimens. The behaviour probably varied with the precise technique used and with what was done after the etching.

He had nothing to say regarding Mr. Legg's comments about the use of the Al/Zn/Mg alloys. He was most interested in them.

He referred now to the increase in temperature and the reaction of the aluminium industry when many aircraft were made of other materials. He did not think they were going to worry about this unduly because they produced a great deal of material for a large number of things other than aircraft. He imagined also that quite a lot of aeroplanes would fly for a long time at speeds this side of the speed of sound.

Special high temperature alloys: sintered aluminium powder was certainly the most hopeful one for temperatures up to 400°C. One could get ordinary alloys that were an improvement on the D.T.D. 364 copper bearing alloys over certain temperature ranges in that he thought they pushed the range of usable temperature up about 30-50 degrees, probably no more.

MR. JONES: There were patents out for a die of the nature Mr. Jones suggested, but he did not know whether such dies had ever been much used, or in fact if they could be used for strong aluminium alloys. There had also been other ways of producing tapered extrusions. Tapered tube had been extruded by using a tapered mandrel on the extrusion ram, and extrusions of other convenient shapes had been tapered by altering the die aperture by similar means.

MR. CONWAY: He was most pleased to hear Mr. Conway's remarks on crack detection and the difficulty of interpretation. He regretted that they had been given the impression that the material supplied was so frequently full of faults. It was not perfectly homogeneous, and personally he was a little doubtful as to where lack of homogeneity became a fault.

Further, regarding tapered sheet, he did not intend giving the impression that it would be easy to obtain. It was obvious that a case would have to be made out in terms of the quantities which would be required and also the certainty that the requirement would not be transient, before decisions to set up equipment could be made.

Regarding the definition of stress corrosion: a material was susceptible to stress corrosion if the corrosion that resulted from a corrosive medium in a given time were increased greatly by the simultaneous application of stress.

MR. LIPSCOMB: The question from Mr. Lipscomb was: were they likely to get materials with consistently high fatigue properties while still retaining a high proof stress? Attempts at improvement were continually proceeding but he did not think they could really hope for a substantial improvement in fatigue. They might get better consistency which he thought was probably the most important point, but that was a difficult problem as well. He thought that improved fatigue properties were more likely to result from improvements in design rather than from improvements in the materials.

Regarding the ratio of proof strength to ultimate strength: for fairly obvious reasons they thought that with a low proof stress but the same ultimate and the same basic fatigue strength a material would give, in a lot of cases, a better life than would the same material with a higher proof. The one thing he hoped would not be asked of the aluminium industry was that they should modify the heat treatment of the present day alloys so that they would have proof stresses intermediate between those of the naturally aged and the artificially aged alloys, since a fully artificially aged material seemed to behave in some respects better than a material subjected to an intermediate ageing treatment.

MR. HAMBROOK: Mr. Hambrook suggested that the shape of an extrusion container and die should follow the lines of flow of the material and should not be sharp cornered as was normally the case. Such curved container-die combinations were, in fact, used with lubricated extrusion conditions as Mr. Hambrook pointed out, but the process was not often utilised, for the reasons already given. The use of such profiled dies for unlubricated extrusion would not result in an improvement in the product and the cost of equipment would be appreciably increased. He could assure Mr. Hambrook that all those things had been well tried out.

He must emphasise that one of the virtues of the existing extrusion process was that the surface of the extrusion came from a comparatively small volume of material which was originally inside the billet and this surface was remarkably free from defects. This surface was much better than could generally be obtained using profiled dies.

Ejection from High Speed Aircraft

by

JAMES MARTIN, O.B.E., F.R.Ae.S.

(Managing Director and Chief Designer, Martin-Baker Aircraft Co., Ltd.)

Introduction

In the earlier days of flying, when aircraft speeds were low, it was a relatively easy matter to resort to a parachute to escape from an aircraft in trouble but, as aircraft speeds increased, escape by means of a parachute was more a matter of good fortune than of personal effort. Early in 1944, with the introduction of jet aircraft into the Royal Air Force, it became apparent that some assisted means of escape would have to be provided to enable air crews to escape from fast jet aircraft in an emergency. It was early in 1944, therefore, that I was invited by the Ministry of Aircraft Production to investigate the practicability of providing, in fighter aircraft, a means of safe escape for the pilot in abandoning the aircraft.

Basic Investigation

I assumed that any designs would have to be suitable for retrospective fit in existing fighter aircraft so a scheme was considered for Spitfires and Hurricanes in which a swinging arm was mounted at the top of the fuselage, with its rear end anchored just forward of the fin, and the front end provided with a "U"-shaped piece engaging rings on the parachute harness. This swinging arm, provided with a powerful spring, was intended when released to raise the pilot out of the cockpit and to throw him clear of the aircraft structure, with the aid of the aerodynamic forces acting upon the swinging arm. A model of this scheme was shown to Sir Stafford Cripps, then Minister of Aircraft Production, and Air Chief Marshal Sir Wilfred Freeman, Chief Executive M.A.P. on 11th October 1944. Both showed keen interest and promised to give all reasonable assistance in this work. I was then informed that the requirement would be not for existing but for new aircraft types.

Ejection by an Explosive Charge

It soon became clear that the most attractive means of ejecting air crews from aircraft in emergency would be by forced ejection of the seat, with the occupant sitting in it, and that the most effective and convenient means of doing this would be by an explosive charge. After ejection, the pilot would fall away from the seat and open his parachute by pulling a rip cord in the usual way. This also fitted in with the Air Staff requirement, at that time, that any ejection seat should be designed to "utilise existing safety equipment."

A Lecture given before the Isle of Wight Branch of the Society on 24th November 1955.

Physiological Considerations

There was, at this time, no information on what the human body could withstand in the form of upward compressive thrust. The experience of lower g, horizontally applied in catapult launching of aircraft could not be applied. It therefore became necessary to see what g the human body could take. I now conceived the idea of shooting a seat up an inclined plane, and by loading the seat to represent the weight of an occupant, to measure the accelerations and rates of rise of g involved. When it became necessary to make tests with human subjects, Mr. Bernard Lynch, one of our experimental fitters, volunteered to have the first ride, and on 24th January 1945, he was shot up the rig to a height of 4 ft. 8 in. In three further tests Lynch was shot up to about ten feet, at which height he reported the onset of considerable physical discomfort. A significant live shot, the 14th, was made with Mr. Andrews of *The Aeroplane* occupying the seat. The day following I learned that Mr. Andrews was in hospital with a crushed spinal vertebrae. As the mean g applied at this time was less than 4 g it became necessary to investigate the nature of the acceleration and the reason for the severe physiological effects produced.

In order to study the structure and physical limitations of the human spine, I arranged to see a number of spinal operations being performed and later obtained a human spine for mechanical tests. From this study and from the records of further tests with the rig, I found that the damaging conditions of the acceleration was a high rate of rise of g, as rates of rise of between 600g per second and 800g per second were being produced. I now realised the importance of a slow rate of rise of g, limited to about 250 to 300g per second, with a peak not to exceed 21g. I came to the conclusion that injury to the spine would not occur if the following conditions were fulfilled:—

(*a*) That the peak acceleration should not exceed 21g and this peak should not be held for longer than about 1/10th second.

(*b*) That the onset, or rate of rise of g, should not be greater than about 250 to 300g per second.

(*c*) That, in sustaining this acceleration, the body should be held in a position to ensure that adjacent spinal vertebrae were square to each other.

From my earliest seats, therefore, the design of gun and cartridge has been arranged to establish the first two basic factors, (*a*) and (*b*), while (*c*) has been obtained by a correct sitting posture in the seat and by the face screen method of firing. These factors are now

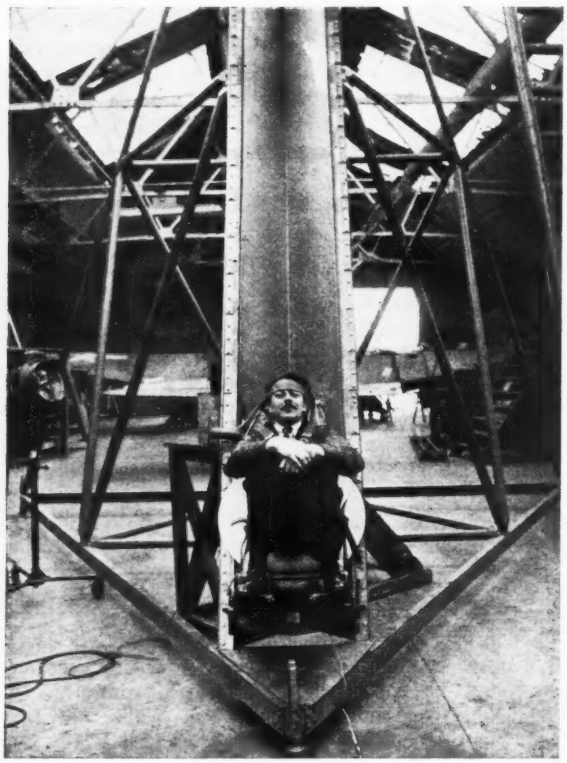


FIGURE 1. The 16 ft. test rig.

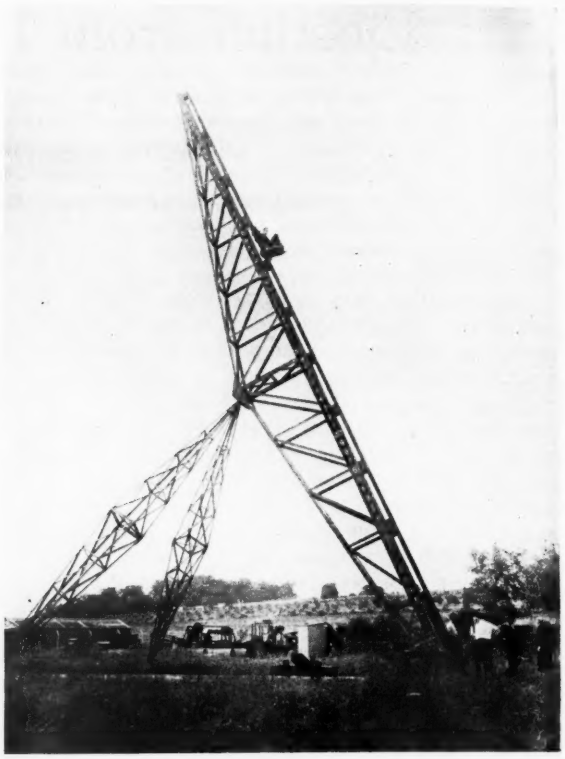
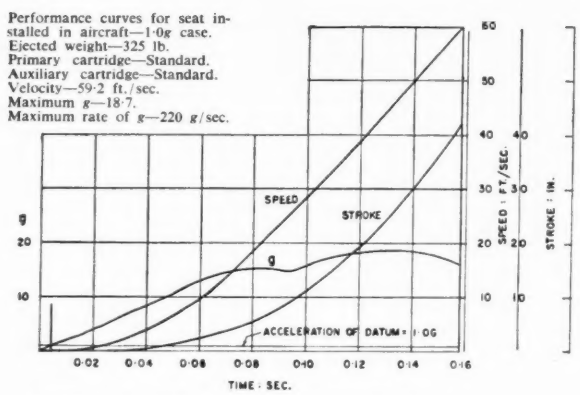
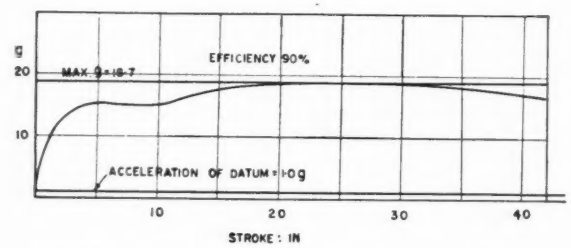


FIGURE 2. The 65 ft. test rig.



Ejection gun performance curves on time base: 1*g* case.



Ejection gun acceleration curve on stroke base: 1*g* case.

FIGURE 3. Martin-Baker ejection seat.

generally accepted and are laid down officially as design criteria for ejection seats. Figs. 1 and 2 are photographs of our early test rigs. Fig. 3 shows diagrams of typical gun performance.

Air Tests from a Defiant

At this stage I was anxious to do some airborne ejections and for this purpose a Defiant aircraft was obtained from the Ministry of Aircraft Production. After the necessary reconditioning and structural alterations, an ejection seat was installed and on 10th May 1945, the seat, loaded with sand bags, was successfully ejected from the jacked-up aircraft into a specially erected catch net. The Defiant was then flown to Wittering and, on the next day, a successful dummy ejection in flight was made, with Mr. Brian Greenstead piloting the aircraft. This was the first ejection from an aircraft in flight in the United Kingdom. On 17th May 1945, six further dummy ejections from the Defiant were made at varying indicated air speeds up to 300 m.p.h. This was rightly regarded by all concerned as an important step forward, the results obtained being encouraging.

Meteor Installation

It was now necessary to consider ejection tests at higher speeds so a Meteor Mark 3 aircraft was obtained from the Ministry of Aircraft Production. The aircraft was modified to enable two pilots' ejection seats to be installed. This work entailed considerable structural

alterations, involving the removal of the cockpit bulkhead, the fitting of a new sloping bulkhead, farther aft, together with the adaptation and strengthening of the ammunition compartment to take the second pilot's seat. On 8th June 1946, a static dummy ejection was made from the jacked-up aircraft and the seat was caught in a specially erected catch net.

On 24th June 1946, an ejection, with dummy, was made from this aircraft at an indicated speed of 415 m.p.h. Due to the unsatisfactory action of a special delay release used in this test the main parachute opened early and burst with the loss of the seat. A subsequent test, with a modified release, gave the same result. During further tests with this release and with a hydraulic type of delayed action release, it was discovered that the stabilising drogue parachute was being drawn in to the wake of the seat and becoming entangled with it. I now conceived the idea of employing a gun and cartridge to extract the drogue and to take it away from the wake of the seat, on a line, whose length was arranged to enable the drogue to develop and control outside the wake turbulence. This proved successful and a drogue gun subsequently became an indispensable feature of Martin-Baker seats. Fig. 4 shows ciné pictures of the effect of extracting the drogue by means of a gun.

I now decided that the time had come to make a live ejection and, on 24th July 1946, Bernard Lynch ejected himself from the Meteor at 8,000 feet at an indicated air speed of 320 m.p.h. The seat worked perfectly and Lynch made a safe landing. This was the first live ejection from an aircraft in this country and was unquestionably a landmark in pilot ejection. On 29th August 1947, Lynch again ejected himself, this time at 12,000 ft. at an indicated air speed of 420 m.p.h. He landed safely and afterwards stated that no shocks had been felt, even at this high speed. This demonstrated the smoothness of the ejection gun, the effective protection of the face screen and the efficiency of the stabilising drogue. Since then Bernard Lynch has made over thirty test ejections and the accumulation of this experience has been invaluable in the development of ejection seats. Moreover, for his courage and bravery he has earned the respect of pilots all over the world.

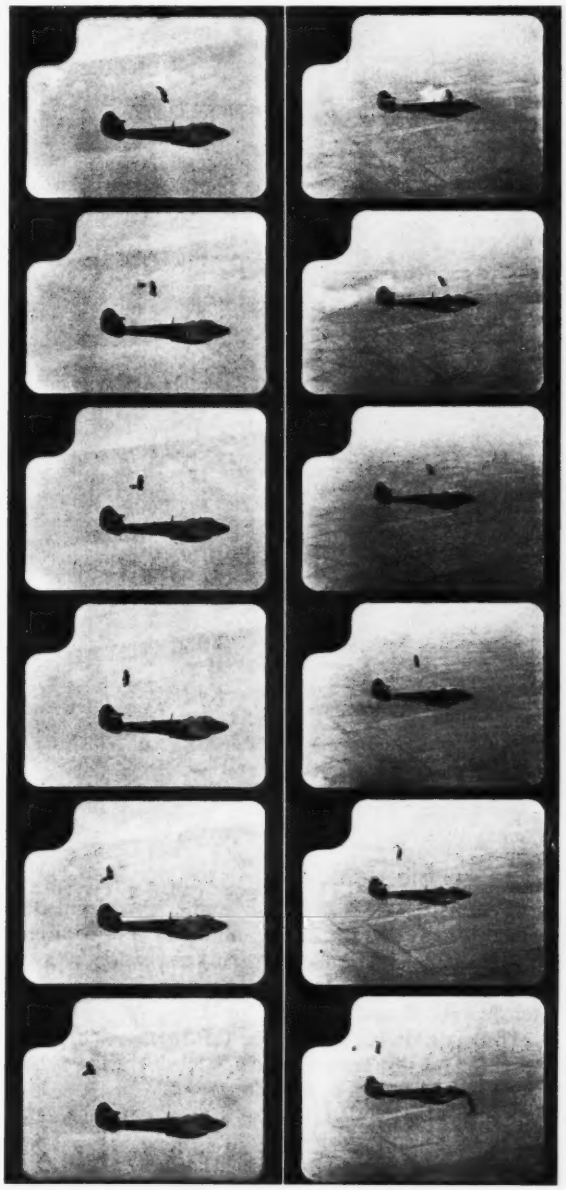


FIGURE 4(*a*). Dummy ejection showing drogue entangled in seat.

FIGURE 4(*b*). Dummy ejection using drogue gun, showing drogue clear of seat.

FIGURE 4.

Work for United States Navy

During this period the U.S. Navy authorities became interested in my work and, on 11th December 1945, Commander J. J. Ide and Lieutenant R. B. Barnes of the U.S. Navy visited the Denham Works and saw a demonstration of the ejection seat and test rig. Subsequently, the U.S. Navy ordered a 110 ft. rig to be erected in Philadelphia; and an ejection seat to be installed in a selected American aircraft for tests. The test rig was erected in the Naval Yard, Philadelphia, by my Company, and the first shot was fired on 15th August 1946, followed by Commander D. W. Gressley taking the first test ride. Further to this work, during the same period, a seat was installed in the rear cockpit of a Douglas A.26 and, under my personal supervision, a test shot from the aircraft on the ground was made, the ejected seat and dummy being caught in a net. This was followed by a series of successful ejections from the aircraft at varying speeds up to 350 m.p.h. A.S.I. culminating, on 1st November, in a successful live ejection from the same aircraft by Lieutenant Furtek, U.S.N. Fig. 5 shows the 100 ft. rig at the U.S. Navy Yard, Philadelphia.

FIGURE 5. The 110 ft. test rig erected at Navy Yard, Philadelphia. First demonstration on August 15th 1946.

Standard Ejection Seat

In June 1947, the British authorities decided to standardise my seat for installation in all new jet aircraft and the work of production and installation was put in hand for Meteor, Attacker, Wyvern, Canberra and later Sea Hawk and Venom aircraft.

The main design features of this seat, which proved so successful in Service, most of which have been retained in later marks of seats are:—

(*a*) Two-cartridge type of ejection gun, designed to give an acceptable pressure curve and high percentage efficiency.
(*b*) The stabilising drogue parachute, extracted by a gun.
(*c*) The face screen method of firing the seat.
(*d*) The adjustable seat pan.
(*e*) The integral thigh guards and adjustable foot-rests.

With this type of manually-operated seat over fifty emergency safe ejections were made from Service aircraft. Satisfying the specification which required the pilot, after ejection, to unfasten the seat harness, fall away from the seat and then to open the parachute by pulling a rip cord, this type of seat undoubtedly justified its introduction in Service aircraft but its limitations were already obvious to me and a means of improving the seat and making the whole sequence of events automatic was engaging my attention.

Automatic Ejection Seats

To cater for cases where, due to battle injury, unconsciousness, or lack of time available when ejected at extremely low altitude, automatic deployment of the main parachute and separation from the seat after ejection was an essential requirement. Effort was, therefore, concentrated on producing a simple, yet effective, automatic conversion set capable of being produced in quantity, reliable, and designed to permit the retrospective conversion of existing manually-operated seats, large numbers of which were already installed in Service aircraft. To this end modification sets were produced and the manually-operated seats, already in Service, were made fully automatic quickly by Service Working Parties and men from my own Works.

To unfasten the seat harness and to uncouple the drogue from the seat after ejection, to enable the drogue to open and stream the main parachute, I designed a main time release mechanism, barostatically controlled and mounted on the seat structure.

Also, to ensure the precise time firing of the drogue gun, a clockwork mechanism was, at the same time, designed to control the firing pin and detonation of the drogue gun charge. This gun replaced the existing static line fired drogue gun.

Main Time Release

The time release consists of spring-loaded plungers, which actuate the harness release and drogue scissor shackle and are controlled by a rack in engagement with gears regulated by an escapement and star-wheel. A barostat control engages the star-wheel at heights in excess of 10,000 ft., delaying the mechanism until that height is reached but, below this altitude, the mechanism has unrestricted movement and begins to function immediately ejection occurs. Barostats set to control at other heights can be fitted if desired. This barostatic control enables the occupant to ride the seat down quickly through the rarified and cold upper air, stabilised by the drogue and supplied with oxygen to the more agreeable altitude of 10,000 ft., when the parachute is automatically deployed. Fig. 6 shows a main time release mechanism.

Ejection Guns

To give an ejection velocity within the acceptable acceleration limits, and thus to produce a seat trajectory to clear the fin of the aircraft, it is necessary to provide a gun of adequate stroke. My early ejection gun, employing two cartridges, had a working stroke of 42 in. and gave an ejection velocity of 60 ft. per second. This gun proved satisfactory in Service for the aircraft of that period. With the advent of aircraft with high fin projections, such as Javelin and "V" Bombers, and in consideration of the higher probable ejection speeds, it became necessary to increase the ejection velocity. Of course, the simplest way of achieving this would be to increase the explosive charge in existing ejection guns. Enough has already been said to show that this easy way out would increase the

peak acceleration and onset of g to an unacceptably high limit and certainly beyond human toleration.

To obtain a high ejection velocity with an acceptable pressure curve there is no substitute for stroke.

A telescopic ejection gun, giving an ejection velocity of 85 ft. per second, while maintaining the characteristically low peak acceleration, and rate of rise of g, of my earlier guns, has been developed and is now fitted in the Javelin and "V" bombers.

This gun consists of three tubes, two of which telescope inside the main outer tube, and is powered by one primary and four auxiliary charges, the latter, for installation convenience, being arranged in two pairs. When the primary charge is fired, the inner tube is unlocked by the generated pressure and, together with the intermediate tube, it begins to extend, carrying the seat and occupant with them. After extending 16 in., two ports are uncovered, allowing the flame to ignite the first pair of cartridges; a further extension of $9\frac{1}{2}$ in. uncovers two other ports to fire the second pair of cartridges.

The gun continues extending until the intermediate tube is arrested by a flange on the outer tube, the shock being cushioned by fifteen circular section hollow gas-filled rings. The inner tube, carrying the seat, continues extending until it breaks away from the gun and from the aircraft.

This gun, of 72 in. stroke, is telescoped to a convenient size and is installationally interchangeable with our earlier standard ejection gun.

Although this gun was designed primarily to give a trajectory adequate to clear the higher fins of some modern aircraft, it has been found, during our recent series of low altitude test ejections at low speeds, to possess the added advantage of gaining trajectory height at low speeds due to the aerodynamic lift obtained by the seat being rotated forward by the

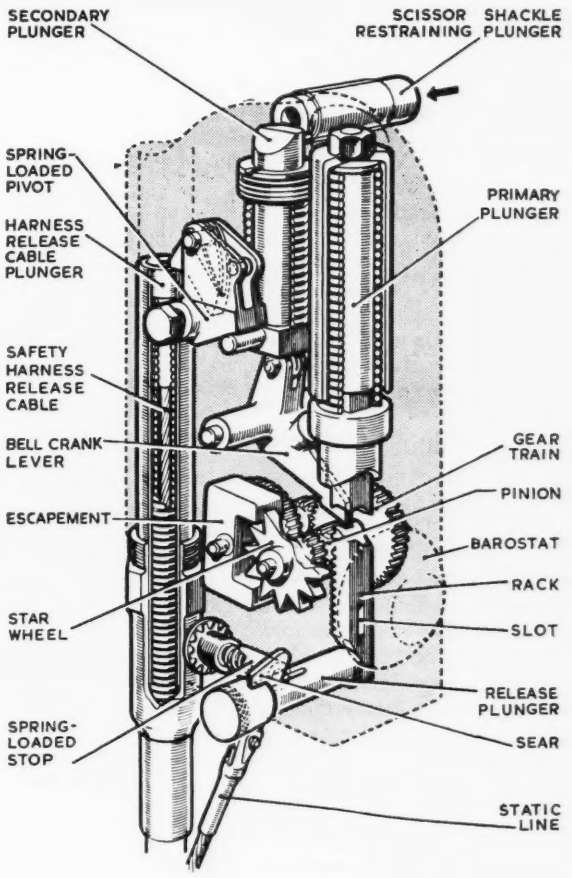


FIGURE 6. Time release mechanism.

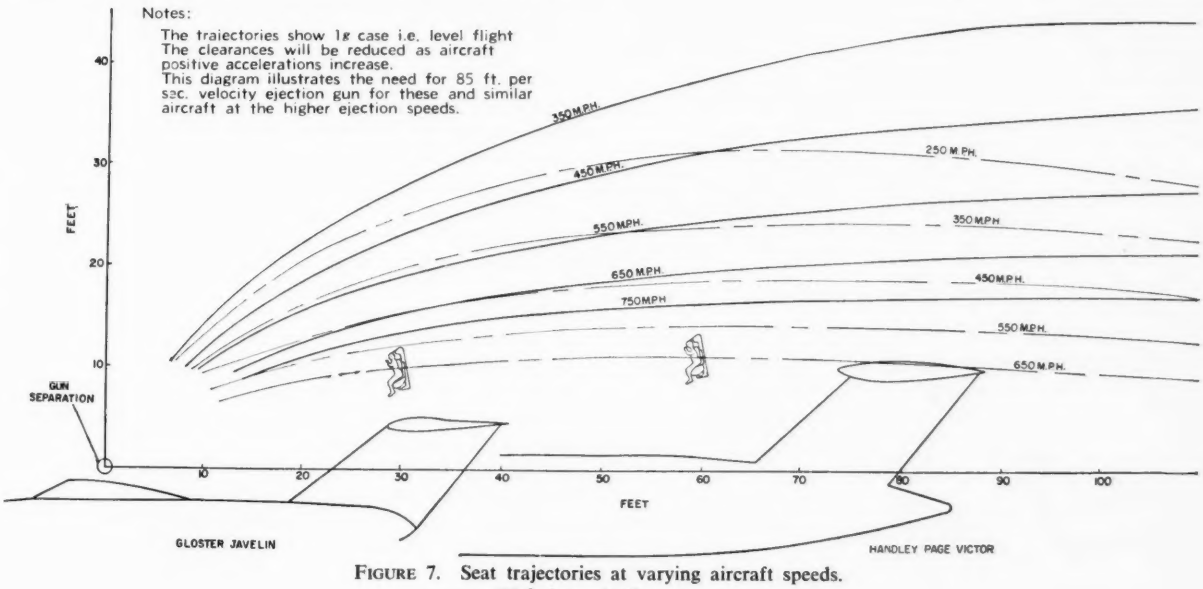


FIGURE 7. Seat trajectories at varying aircraft speeds.
——— 85 ft./sec. ejection gun.
— - — 60 ft./sec. ejection gun.
1g case Level flight.

increased duration of the thrust. Trajectory heights of the order of 90 ft. above aircraft datum are obtained, with this gun, at indicated air speeds of about 150 m.p.h. and this enhances the chances of safe escape at low speeds near the ground, a most difficult combination. Analysis of our test records shows that a gun of at least 85 ft. per second is essential to clear the fins of Javelin and "V" Bombers at the probable ejection speeds of these aircraft.

Squadron Leader Fifield used this gun for his runway ejection, on 3rd September 1955, and afterwards said that it gave him a remarkably smooth ride. Fig. 7 shows trajectory curves of 60 ft. per second and 85 ft. per second guns, at 1g with a Javelin and Victor Tail Unit superimposed on the same scale. This illustrates the need, in these and similar aircraft, for the 85 ft. per second velocity gun.

Leg Restraining Harness

Experience of ejection has shown the need to restrain the legs against flailing during ejection to prevent injury. Footrests and thigh guards alone are not adequate to deal with this problem at the higher ejection speeds: we have therefore developed and put into service a Patent Automatic Leg Restraining Device.

This consists of two reinforced nylon cords, one end of each cord being connected to the cockpit floor by means of a roller bracket, designed to pull away at the load required to ensure that the legs are held together firmly on the forward edge of the seat pan. The other end of each cord is passed through snubbing units fixed to the forward face of the seat pan, then through metal rings, carried on webbing garters, which the wearer straps to his legs. The two free ends are then connected to the harness release box or, in the case of the combined parachute and seat harness, to the two bottom harness points on the seat pan.

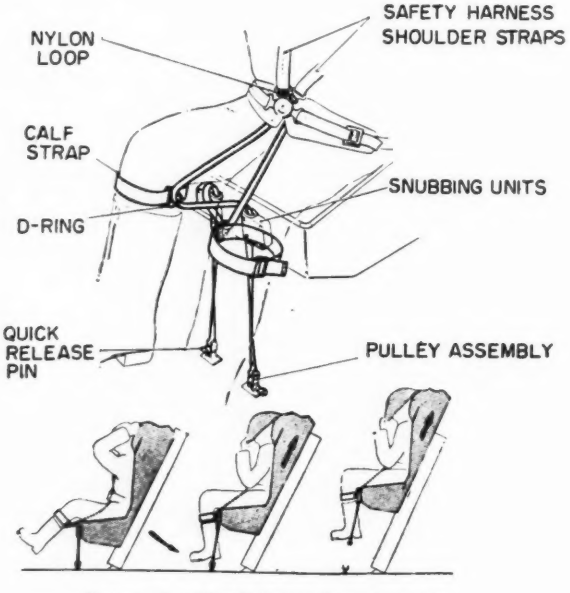


FIGURE 8. Martin-Baker Leg Restraint.

The cords are arranged to allow free movement of the legs in the cockpit but, on ejection, the cords tighten up between the snubbing units and harness box, thereby automatically securing the occupant's legs to the seat pan, where they are firmly held until the harness is unlocked and the occupant is separated from the seat. This installation, simple in design, is an indispensable safety feature on modern ejection seats. Fig. 8 shows the arrangement of Leg Restraint.

Duplex Drogue

A stabilising drogue parachute, automatically extracted and deployed after ejection by means of a gun, to take it clear of the wake of the seat, has been an essential feature of Martin-Baker Ejection Seats from the earliest designs. My idea of casting off the drogue automatically from the seat, after a suitable time interval following ejection, and further utilising the drogue to stream the main parachute, is unique in automatic ejection seat functioning. Martin-Baker Patent Fully Automatic Ejection Seats, employing this method of operation are already installed in Service aircraft.

A drogue parachute of constant canopy size will only achieve optimum efficiency at a certain speed and altitude combination. In other conditions its performance will be less efficient. A further factor is that it is unsafe to deploy an uncontrolled parachute at the highest probable ejection speed and this fact places a serious limit on the use of uncontrolled parachutes for very high speed ejections. Taking these factors into account, the Fully Automatic Ejection Seat formerly employed a 24 in. diameter drogue which streamed the main parachute five seconds after ejection. This time interval, with this particular drogue, was selected to allow the speed to drop from the highest probable ejection speed to one safe for opening the main parachute.

Action of Duplex Drogue

Although this arrangement has proved successful in Service aircraft, I was impressed with the need of speeding up separation from the seat after ejection, in order to reduce the minimum altitude at which safe ejections were practicable. Intensive development work and flight testing with various types of drogues led to the introduction of the Duplex Drogue which has now been introduced in Service ejection seats. The Duplex Drogue scheme employs two stabilising drogues in tandem, a small drogue, known as the controller drogue, and a larger main drogue. The controller drogue is automatically extracted by a drogue gun after ejection and, when deployed, brings the seat back into a horizontal attitude and then tows the main drogue out of its container. The main drogue then streams the parachute, which, when developed, lifts the occupant out, the seat falling away cleanly to the ground. The action of the controller drogue secures two indispensable aims, first, to get the seat into a horizontal attitude so that the subsequent deceleration on the seat and occupant is linear and consequently more tolerable; secondly and most important, it prevents explosive opening of the main drogue. In our tests, when a 5 ft.

diameter drogue was deployed at 600 m.p.h., at a height of 150 ft., without a controller drogue, it was torn to shreds; also the large drogue produced such violent loads that the face screen was torn and seat harness shoulder straps were broken. Six tests in similar conditions were done with a controller drogue employed and these were all satisfactory, none of the components showing any signs of distress. The main drogue in turn prevents, in the same manner, explosive opening of the parachute, thus opening shocks and decelerations are reduced to a magnitude within the strength limitations of the parachute and the physical limitations of the body. With this arrangement the main parachute can be safely deployed at very high speeds after three seconds, or after one and a half seconds at low air speeds.

Figure 9 shows, in diagrammatic form, the action of the Duplex Drogue.

Escape Conditions

When considering escapes from an aircraft by means of an ejection seat, the height, speed, aircraft behaviour and attitude at the time of ejection are significant factors, although we have found that aircraft behaviour is usually only of minor importance, except when the ejection altitude is extremely low.

Three difficult conditions present themselves in escape from aircraft, namely:

(*a*) Lack of altitude combined with low forward speed.
(*b*) Extremely high altitude.
(*c*) High speed.

Low Level Ejection

A series of fatal accidents, in single-engined fighter aircraft of the Navy and Royal Air Force, when the pilots ejected near the ground or sea, following engine failure soon after take-off, impressed upon me the need to provide facilities for safe ejection from runway level.

In an ejection near the ground, or immediately after take-off from an aircraft carrier, split seconds count and no time at all must be wasted.

Safe escape near the ground is fundamentally due to the method and speed of deploying the main parachute. To bring this about, the seats are fitted with two stabilising drogue parachutes in tandem, the leading controller drogue being extracted from its stowage by a time-fired drogue gun, which is triggered off on ejection. As previously described, this small drogue brings the seat into a horizontal attitude and tows a larger drogue out of its container. The deceleration of the seat is now taken linearly and "explosive" opening of the large drogue eliminated by the action of the controller drogue. In the same manner the sustained pull of the large drogue prevents explosive opening of the main parachute. While these drogues are at work, away from the wake of the seat, the time-release mechanism is running to open the seat harness and uncouple the drogues from their attachment. As soon as the drogues are cast off, they pull out the parachute pack pins and stream the main parachute. When developed, the parachute lifts the occupant cleanly out of the seat, sticker straps being provided to prevent collision during separation. Because of the forward speed component and the efficient pull of the drogues, all this occurs with insignificant loss of height.

Another important factor of safe escapes near the ground is a high seat trajectory. As stated earlier, this is accomplished on later Martin-Baker seats by fitting a long stroke, telescopic gun, giving an ejection velocity of 85 ft. per second. This gun, with low peak acceleration and mild onset of *g*, gives a smooth ride to its occupant, taking him safely clear of the fin, at the highest probable ejection speeds and, at slow speeds, near the ground it increases the effective height for parachute deployment.

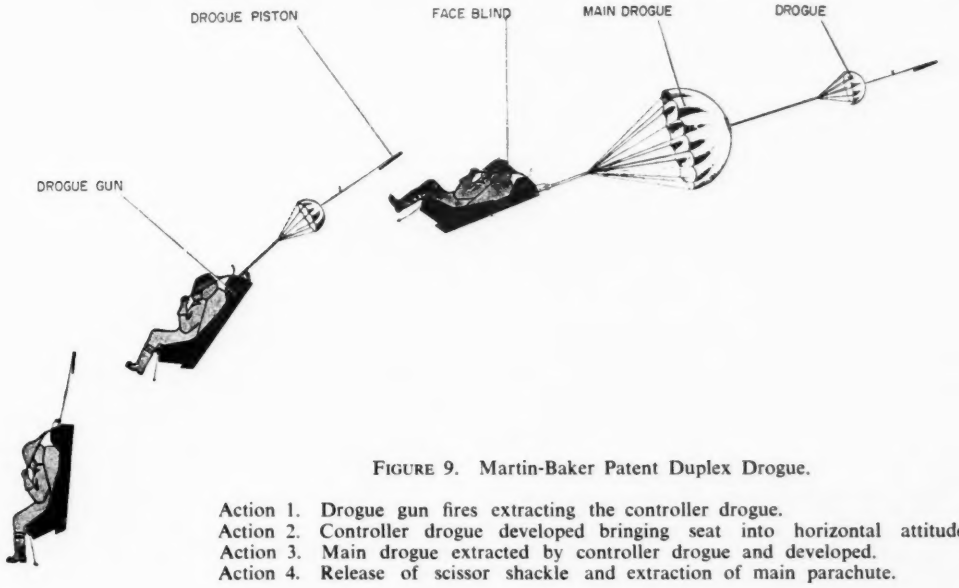
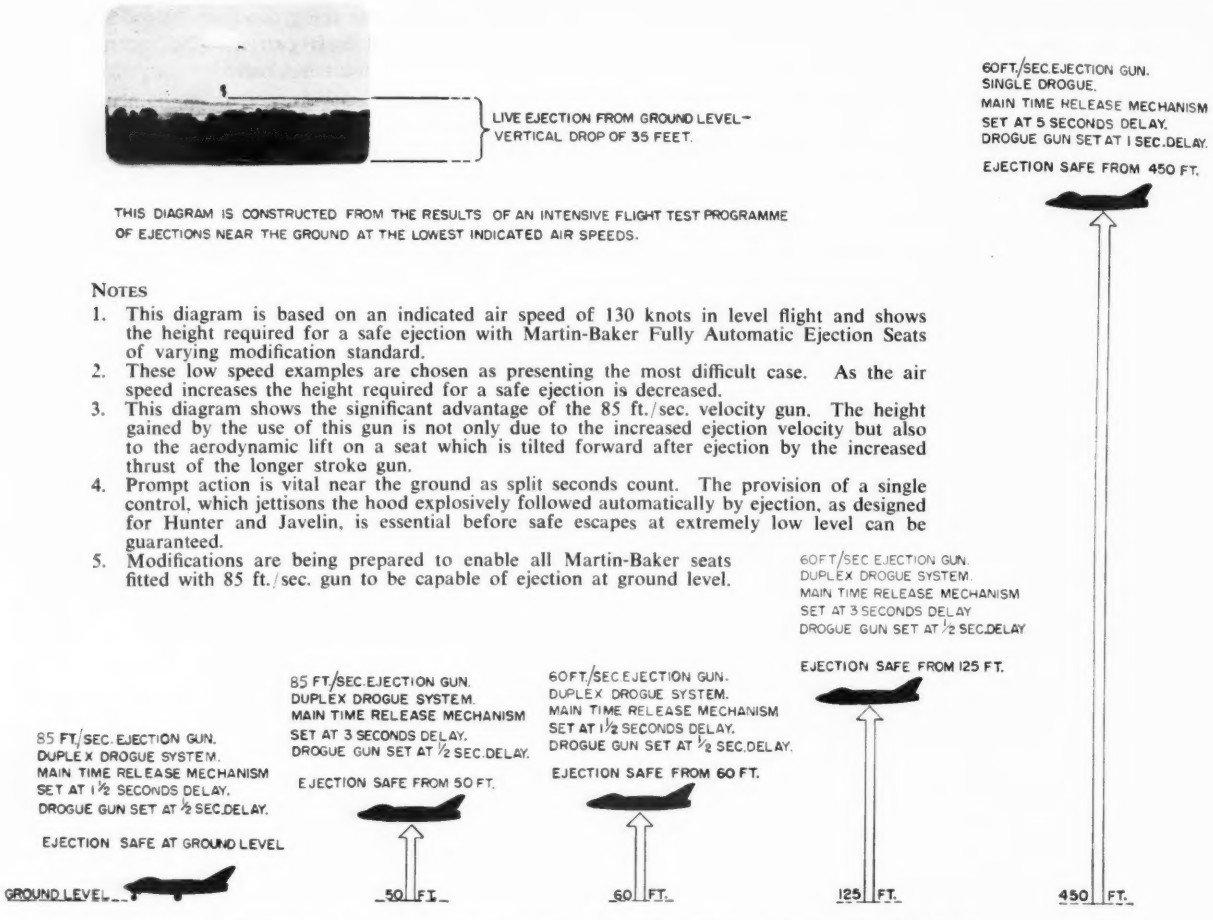


FIGURE 9. Martin-Baker Patent Duplex Drogue.

Action 1. Drogue gun fires extracting the controller drogue.
Action 2. Controller drogue developed bringing seat into horizontal attitude.
Action 3. Main drogue extracted by controller drogue and developed.
Action 4. Release of scissor shackle and extraction of main parachute.


LIVE EJECTION FROM GROUND LEVEL—
VERTICAL DROP OF 35 FEET.
THIS DIAGRAM IS CONSTRUCTED FROM THE RESULTS OF AN INTENSIVE FLIGHT TEST PROGRAMME OF EJECTIONS NEAR THE GROUND AT THE LOWEST INDICATED AIR SPEEDS.
60FT./SEC.EJECTION GUN.
SINGLE DROGUE.
MAIN TIME RELEASE MECHANISM
SET AT 5 SECONDS DELAY.
DROGUE GUN SET AT 1 SEC.DELAY.
EJECTION SAFE FROM 450 FT.
60FT/SEC EJECTION GUN.
DUPLEX DROGUE SYSTEM.
MAIN TIME RELEASE MECHANISM
SET AT 3 SECONDS DELAY
DROGUE GUN SET AT ½ SEC.DELAY
EJECTION SAFE FROM 125 FT.
85 FT./SEC.EJECTION GUN.
DUPLEX DROGUE SYSTEM.
MAIN TIME RELEASE MECHANISM
SET AT 3 SECONDS DELAY.
DROGUE GUN SET AT ½ SEC.DELAY.
EJECTION SAFE FROM 50 FT.
60FT./SEC.EJECTION GUN.
DUPLEX DROGUE SYSTEM.
MAIN TIME RELEASE MECHANISM
SET AT 1½ SECONDS DELAY.
DROGUE GUN SET AT ½ SEC.DELAY.
EJECTION SAFE FROM 60 FT.
85 FT./SEC.EJECTION GUN.
DUPLEX DROGUE SYSTEM.
MAIN TIME RELEASE MECHANISM
SET AT 1½ SECONDS DELAY.
DROGUE GUN SET AT ½ SEC.DELAY.
EJECTION SAFE AT GROUND LEVEL
GROUND LEVEL
50 FT.
60 FT.
125 FT.
450 FT.

NOTES

1. This diagram is based on an indicated air speed of 130 knots in level flight and shows the height required for a safe ejection with Martin-Baker Fully Automatic Ejection Seats of varying modification standard.
2. These low speed examples are chosen as presenting the most difficult case. As the air speed increases the height required for a safe ejection is decreased.
3. This diagram shows the significant advantage of the 85 ft./sec. velocity gun. The height gained by the use of this gun is not only due to the increased ejection velocity but also to the aerodynamic lift on a seat which is tilted forward after ejection by the increased thrust of the longer stroke gun.
4. Prompt action is vital near the ground as split seconds count. The provision of a single control, which jettisons the hood explosively followed automatically by ejection, as designed for Hunter and Javelin, is essential before safe escapes at extremely low level can be guaranteed.
5. Modifications are being prepared to enable all Martin-Baker seats fitted with 85 ft./sec. gun to be capable of ejection at ground level.

FIGURE 10. Performance diagram for Martin-Baker Fully Automatic Ejection Seats. Illustrates limitations with varying ejection gun, timing and drogue combinations.

The secret of safe escapes near the ground is to get the parachute deployed speedily after ejection, say within one and a half seconds. In Martin-Baker fully-automatic seats, this sequence begins immediately ejection is initiated, indeed in the accelerated case, the parachute is ready to come out by the time the top of the trajectory is reached. This, of course, would be too fast at very high speeds.

In the latest seats, the time release mechanism will be fitted with a sensing over-ride*, which will automatically select the time required for safe deployment of the parachute, to meet the conditions of speed prevailing at the time of ejection.

In low level ejections another vital requirement is that the escape facilities of the aircraft must not prejudice the chances of the pilot to escape in an emergency.

When a pilot wishes to abandon an aircraft, quick action is vital. There must only be one control to operate to fire himself out. Stick snatching and power-operated hood jettisoning must be linked to the ejection seat operation, in a manner which will ensure safe and speedy ejection, by the operation of the seat firing mechanism only. With the right kind of equipment low level ejection, including runway ejection, is now practicable. Squadron Leader Fifield's live ejection from a Meteor taking off at Chalgrove on 3rd September 1955 was the culmination of an intense test programme with dummies shot out on the runway and it was designed to show how safe escapes could be made right down to the ground. It also converted the sceptics, who were previously convinced that a man would not survive such an ejection. Fig. 10 shows the height limitations with various combinations of ejection gun and timing. It illustrates the need, in the low speed case, for a gun of 85 ft. per second ejection velocity and the time release mechanism set at 1½ seconds. Squadron Leader Fifield on this occasion was safely on the ground six seconds after firing himself out of the Meteor. For this test a standard Mk. 3 ejection seat was used, with the

*Since this paper was written the sensing device referred to, which will make ejections possible on the runway, has now been developed and tested. Action will be taken at an early date to have this device incorporated in latest type seats, and in conjunction with the 85 ft., per second gun, ground level ejections will thus be made possible.

main time release mechanism set at 1½ seconds delay. A standard 24 ft. Irvin air chute was used. It is interesting to note, that for this test, Squadron Leader Fifield would, at first, have preferred a 28 ft. diameter parachute, but when their respective performances, as recorded on our ciné films, were compared it was seen that the 24 ft. diameter parachute developed quicker thus giving a longer free drop, the height in this case being 35 ft.

I consider that an essential requirement of a modern ejection seat is to provide for safe escapes right down to ground level. Pilots of naval aircraft which suffer engine failure immediately after take-off from an aircraft carrier, will, with the latest seat, be able to fire themselves out before their aircraft hits the sea and alight safely in a fully developed parachute. Naval air crew are unlikely to overlook this vital facility. In land-based aircraft operations many occasions arise when the crew could escape fatal injury by a safe ejection at ground level during a hazardously abortive take-off, or approach to land.

High Level Ejections

It seemed from our tests and service experience, that ejections up to the service ceiling of present-day aircraft were practicable. I was, however, anxious to find out, by means of a live ejection from 40,000 ft., what it was like to ride the seat down from this altitude to the separation altitude of 10,000 ft. So, on 25th October 1955 Squadron Leader J. S. Fifield made a test ejection from a Meteor Mark 7 from 40,000 ft., using a standard Martin-Baker Mark 3 seat.

As previously described, the time release mechanism of this seat was barostatically controlled to bring the seat quickly down from 40,000 ft. through the cold and rarified upper atmosphere to 10,000 ft., where parachute deployment and separation from the seat took place.

During this controlled descent the occupant has the protection of the seat structure and face screen, leg flailing is prevented by the automatic leg restraint, while the firing handle provides a positive hand hold and this takes care of the arms.

The face screen also holds the oxygen mask in position on the face enabling the pilot to breathe the oxygen which has been turned on as the seat ejects.

Wing Commander F. Latham, R.A.F. Institute of Aviation Medicine, with the aid of a powerful telescope, saw Fifield leave the aircraft and watched his descent. Wing Commander Latham said that for the first 15 seconds of the fall the seat was fully stabilised. Thereafter the seat settled to a slow spin, of from 15 to 20 r.p.m. about the longitudinal axis, until it disappeared into a patch of stratus cloud. When seen again Fifield was in his parachute. Afterwards, Squadron Leader Fifield stated that he did not feel any unpleasant sensation from this and that the seat was remarkably stable throughout the descent. From this test it is concluded that, with this type of seat, safe ejections from 40,000 ft. and higher are practicable and that the stability of the seat enables it to be ridden down in safety and comfort.

High Speed Ejection

In a high speed ejection, the requirement is to protect the body from the damaging effect of the air blast and to slow the seat down, with acceptable decelerations, to a speed at which it is safe to deploy the parachute. Looking back it is interesting and significant to note that it was considered that a fatal result would ensue from shooting a man out of an aircraft at an indicated air speed of 300 m.p.h. When Bernard Lynch survived this and, indeed, the much higher ejection speed of over 400 m.p.h. I.A.S., we began to gain confidence and safe ejections, with only very minor injuries, have already occurred in service at speeds up to just over an indicated speed of a Mach number of one. On 3rd August 1955, Flying Officer H. Molland ejected at 25,000ft. from a Hunter diving at an indicated Mach Number of 1·1. This was in a Mark 2 series seat, not fitted with leg restraint and the aircraft did not have explosive canopy jettisoning arrangement, linked to the ejection seat firing mechanism. The broken arm and "two black eyes" sustained by Molland were caused by his not having the full protection of the blind, as he used only the left hand to pull the firing handle, the right hand, at the time, being used to operate the hood jettison control. He would probably not have received these injuries with the latest scheme in which the aircraft hood is explosively jettisoned, followed by ejection, with the operation of a single control.

The automatic leg restraint, firing handle grip and face screen provided in Martin-Baker seats seem to give satisfactory protection up to speeds of the order of 600 m.p.h. and the need has not yet arisen for any further body protection. When considering probable ejection speeds, it is wise to study reports of ejections up to the present time. From this study it will be seen that ejections at the higher speeds of aircraft capability are rare and somewhat exceptional. Pilots wishing to escape, will, when possible, reduce speed and speed will also be reduced by the rapid rise of drag of an aircraft breaking up, following air collision or structural failure. Although it is right and proper to cater for the highest speed, it will invariably be found that most emergency ejections will lie in the more modest speed ranges, say between 40 per cent. and 80 per cent. of the aircraft's top speed.

I see a need, as probable ejection speeds increase, to provide additional body protection, particularly in the chest region, and this could be provided in the seat structure.

What about the structural limitations of the parachute equipment?

The problem is two-fold; first, to reduce rapidly, with acceptable decelerations, the speed of ejection to a speed at which it is safe to deploy the parachute and secondly, at the same time to prevent "explosive" opening of the canopy, which is so damaging and can be fatal. The Duplex Drogue system, as described earlier seems to deal with this problem adequately. From our work and service experience there is no reason to doubt that the decelerations required to reduce the probable ejection speeds of the immediate future to the

safe deployment speed will be other than tolerable, if that deceleration is applied and controlled in the way outlined.

The need has already been stated for explosive jettisoning of the aircraft hood, coupled automatically with the ejection sequence, calling for the operation by the pilot of a single control only in emergency. This is essential for low altitude escapes, and in the high speed case it gives the crew the protection of the hood while the ejection control is being operated. A Martin-Baker scheme is available for this and is at present installed in later types of Service aircraft. During our tests we applied loads of up to 1,500 lb. by placing lead shot bags on the hood and then shooting it off. Tests in front of the blower tunnels show these schemes to be sound and practicable and, when fitted on aircraft, will greatly improve the chances of safe escape, particularly near the ground and at high ejection speeds.

I consider that high speed ejections from the present breed of fighters and from those immediately to follow, will not present problems which cannot be met with our latest type of ejection seat.

FUTURE DESIGNS

Downward Ejection

Because there has been no requirement in a British aircraft for a downward ejection seat, our work on this subject has been confined to a design study. This has led us to the conclusion that there are no special problems but many disadvantages in downward ejection.

In most British aircraft escape exits are provided in the roof of the crew compartment and it is therefore attractive, structurally, to use these exits through which to eject. To provide downward ejection would mean additional exits in the floor. This would impose an aircraft structure weight penalty and would further complicate control and plumbing runs, especially in fighter aircraft.

Some designers were attracted to downward ejection because of a supposed limit in the performance of ejection guns, for upward ejection. Our long stroke gun, with an ejection velocity of 85 ft. per second, is adequate to clear the fins and elevated tail units, such as Javelin and "V" Bombers. Ability to eject at ground level is so essential that—for this reason in particular—upward ejection should not be discarded in favour of downward ejection.

Capsule or Pod Ejection

What of capsule, or pod ejection?

No serious minded aeronautical engineer is likely to overlook the immense problems, aerodynamic and engineering, of this type of escape.

In the engineering field the designer will have to arrange the structure to accommodate the crew and all flight facilities within the pressure capsule, provide instant separation cleanly in emergency and get it away, itself undamaged, from the aircraft in distress.

After separation, the aerodynamic performance is vital. Stabilisation and retardation must be arranged. Then the capsule must be landed, or the crew ejected from it at a selected altitude and brought down safely by parachute. Time would be required for this deployment and, although obvious advantages would accrue from the use of a capsule at extreme altitude, it would be quite impossible to do a low escape—say runway level—with a capsule.

Conclusion

Looking back on ejection seat development during the past eleven years I think the progress made is impressive, particularly when one considers the problems involved in getting a pilot safely away from a high speed aircraft in the difficult conditions attending the usual emergency ejection. We have now the accumulated experience of over one hundred and fifty emergency ejections, including one ejection at a speed greater than a Mach number of one and many lessons have been learnt from these ejections. We have made hundreds of test ejections in varying conditions and combinations of components. Live tests have been successfully executed at representative altitudes from the runway to 40,000 ft. and at indicated air speeds from 150 m.p.h. up to 500 m.p.h. at sea level.

While not content to dwell on past achievements, we shall, of course, press on to design escape equipment for the next breed of newer types of aircraft.

We are often reminded that the days of the manned fighter and bomber are numbered. Be that as it may, I believe that while they remain in their present or predicted form, an ejection seat can be provided which will offer a safe means of escape in most emergency conditions.

A Fixture for Testing Sheet Materials in Compression at Elevated Temperatures

by

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(Metallurgy Department, Royal Aircraft Establishment)

SUMMARY: Supersonic speeds of flight have brought thermal problems due to the kinetic heating of skin materials. These materials, generally metallic, suffer loss of strength and stiffness with increase in temperature and a knowledge of changes in value of these properties at elevated temperatures is a pre-requisite to a design study. More particularly for stress offices the compressive stress-strain curves are required from which are derived tangent- and secant-moduli used to predict buckling in components. A fixture has therefore been developed for testing under edgewise compression sheet materials up to temperatures of 400°C.

1. Introduction

Due to difficulties inherent in edgewise compressive testing of sheet material, comparatively little work has been done in experimental determination of sheet mechanical properties, particularly at elevated temperatures. Lateral elastic instability of the loaded specimen is perhaps the greatest single obstacle. Side support against buckling, either local or general, must introduce a minimum of frictional resistance and little restraint to deformation of the specimen undergoing dimensional changes in all directions simultaneously.

Stability has been achieved in a " pack "[1] of similar test pieces, held or cemented securely together to constitute a composite specimen, but this method is wasteful of material and time. Single-specimen fixtures for use at room temperature have been developed and in the U.S.A. have proved successful using solid guides[2], but these guides require lubrication for satisfactory results. Moreover, the thickness of the film of lubricant between guides and specimen was found to be dependent on the stiffness of the material and the amount of initial curvature in the specimen inherited from the rolled sheet.

An evaluation of the friction present in a lubricated solid-guide fixture of Dutch design has been made and reported[3].

To reduce friction, rollers, spaced transversely by springs, have been used[4]. Thus the longitudinal or greatest deformation of the specimen is opposed by rolling friction; the lateral friction is, however, that of solid unlubricated guides. Thin specimens also tend to buckle prematurely between rollers.

For tests up to 150°C. a fixture has been immersed in a heated oil-bath[5]. Apart from the inconveniences introduced by a bath, the use of oil or grease as a lubricant will limit the maximum testing temperature to something considerably below 400°C.

The application of high stress through the top edge to thin sheet in a compression fixture presents difficulties. Stability, which is unavoidably least at the top edge when the latter projects beyond the guides, is reduced by any errors in parallelism between loading platen and specimen end, by slight curvature often present in the plane of the sheets, and by play of the testing machine crosshead within its guides. Despite this the general practice has been to leave the specimen end above the guides to allow the top loading platen to follow up specimen deformation.

The insertion of a subpress customary for room temperature compressive testing, with close working clearances to minimise side play, was considered impractical; the fixture developed employs a guided anvil relatively small in mass, thus helping to lessen heat conduction losses and also reducing the working zone in the furnace.

To overcome some of these disadvantages it was decided to develop a fixture employing steel balls as the antifriction media, having the top edge of the specimen below the top of the guides and arranging the anvil to align automatically with the platen.

2. Description of Fixture

The fixture, shown in Fig. 1, consisted basically of a mild steel pillar of substantial rectangular cross section with two stabilising feet which served also to locate the unit in the testing machine.

For simplicity both the fixture body and the extensometer were made in mild steel and by a suitable arrangement of asbestos heat-shielding, objectionable differences in temperature within the apparatus were minimised.

A clamp surmounting the pillar held the specimen between guides which maintained 1/16 inch diameter steel balls in contact with the specimen. On one side of the clamp a movable guide, adjusted by two dome-ended grub screws fitting into a vee groove, permitted sufficient alignment to accommodate the irregularities normally met with in commercial sheet and provided at the same time adjustment for thicknesses of sheet from 0·25 inch downwards. The guides, fully hardened high-speed tool steel, which would not soften appreciably below 500°C., were ground and carefully polished on

Originally received November 1955
Revised April 1956

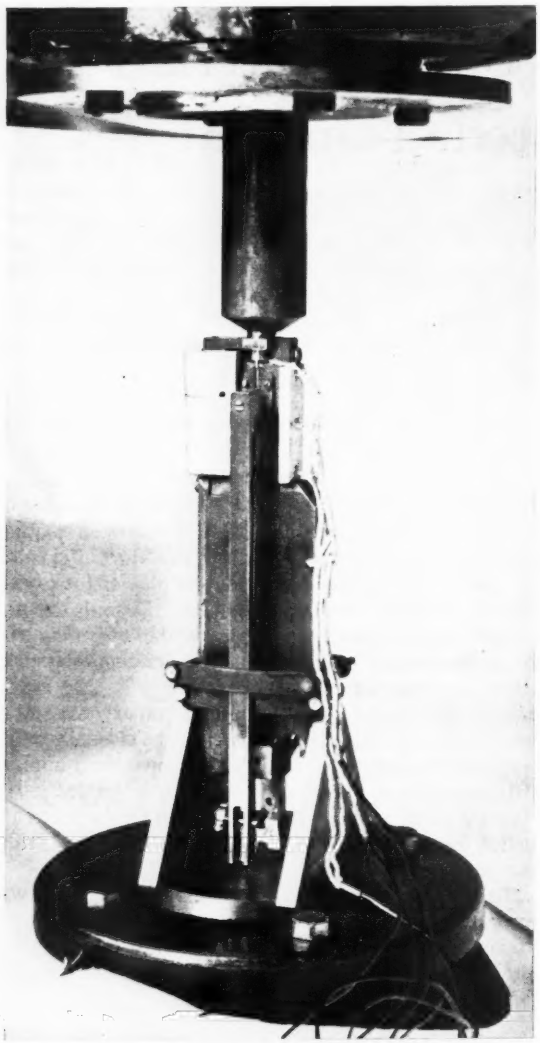

FIGURE 1. Compressive fixture with furnace removed.

the faces adjacent to the specimen. The clamp with a specimen in position is shown in Fig. 2, while Fig. 3 shows the clamp details. A brass cage, one to each guide, spaced the balls evenly and a sufficiently large ball-pocket permitted each ball to roll independently in the direction of local deformation on the surface of the specimen. The direction and displacement of any ball will depend upon its position in the cage; displacement is greatest in the axial direction for the uppermost rows and lateral displacement is greatest for outermost rows of balls. As the relative displacement of the clamp and ball is half that of the clamp and specimen, clearance between ball and cage may be small enough to retain the ball, yet permit free rolling sufficient for specimen deformation beyond the 0·5 per cent proof stress.

Even if closely spaced, rollers of the smallest practical diameter used to support thin sheet under increasing compressive stress eventually permit inter-roller buckling. The onset of this local elastic instability was

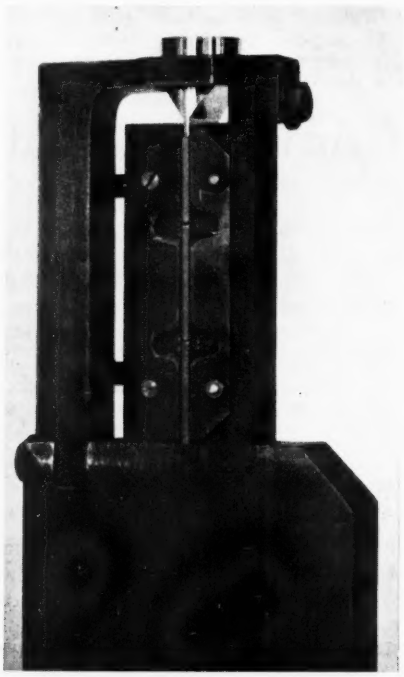

FIGURE 2. Compressive fixture clamp.

deterred in the present design by arranging rows of balls obliquely to the longitudinal axis.

Stability and alignment between loading platen and specimen were promoted by inserting a loose anvil which automatically squared up to the top platen and was positioned relative to the top edge of the specimen by the first row of steel balls.

3. Test Piece

A gauge length of one inch was considered most practical for this fixture.

It has been established that " end effects " arising at the platens extend deeply into a body under compression and uniform stress occurs only in slender specimens at some distance from the ends[6]. An overall length of specimen of 2·625 inches gives a region of substantially uniform stress within the central one inch, the length embraced by the extensometer.

To promote alignment of the applied load and test piece axis, care was taken to machine each specimen parallel and square. The effect, however, of any small extraneous misalignment of these axes in the plane of the specimen is compensated for by the design of extensometer which, measuring the strain on both edges of the specimen simultaneously, records the average strain across the section.

4. Extensometers

To measure the compressive strain a roller-type optical extensometer, similar in principle to one extensively used for tensile testing at elevated temperature, was adapted. In this instrument the relative displacement of the top and bottom gauge points was

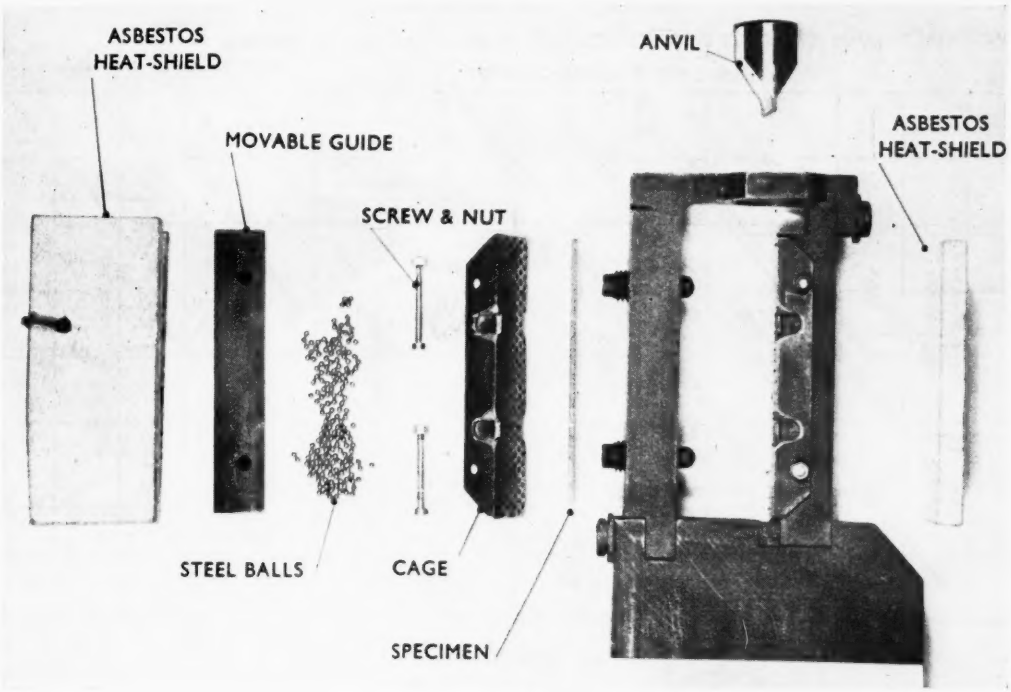

FIGURE 3. Details of clamp.

transmitted by vertical legs down to a roller and mirror near the base. Rotation of the mirror caused the image of a scale at 100 inches distance, as viewed through a telescope, to magnify × 3,000 the contraction taking place between the gauge points.

5. Temperature Measurement

Temperature was measured at three points by thermocouples, shown in Fig. 1, housed in pockets sunk in the fixed guide to within 0·06 inch of the working face. One thermocouple was placed at the mid-point and one near each end of the specimen.

The specimen under test was held centrally in a cylindrical electric furnace provided with adjustment of heat output at the ends to correct for losses. This furnace was permanently sealed at the top but open at the bottom for unobstructed movement of the extensometer. Air convection currents over the extensometer mirrors impaired only slightly the images of the scale in the telescope.

6. Development

For compressive testing of thin sheet at room temperature the suitability of fixtures employing lubricated solid-guides has been established[2]. It was decided, therefore, to make a direct comparison of results obtained in the same fixture from tests using balls and corresponding tests using solid-guides. At the same stresses no differences in recorded strains would indicate that frictional resistance, restraint to lateral expansion, and the tendency to general or local elastic instability was equivalent in both systems.

Since the elastic instability of a long member in compression is a function of modulus of elasticity and least moment of inertia of the section (Euler), aluminium alloy, low in elastic modulus, was considered suitable material for these development tests. Furthermore, an aluminium alloy sheet coated with soft aluminium (Alclad) would not only buckle easier than the homogeneous sheet of equivalent material and thickness, but would also constitute an exacting test for detection of ball indentation of the soft surface.

Using greased solid-guides and ball-support, stress-strain values from tests made within the elastic range on coated aluminium alloy D.T.D. 610 are given in Table I and Figs. 4 and 5.

Reproducibility in the ball system is shown, in Fig. 4, to be superior to the greased solid-guides since loading and unloading readings produced a friction hysteresis loop only in the later case. It would appear, therefore, since rolling friction results principally from deformation of the surfaces in contact, that very little elastic indentation by the balls of the soft aluminium surface cladding was present.

Detection of the slight differences of slope in the linear portions of a stress-strain graph, arising from primary and secondary modulus of elasticity met in aluminium-coated sheets, requires sensitive apparatus. In this respect, the sensitivity of the lubricated guides and the ball method of support is shown to be similar by the stress-strain curves of Fig. 5, wherein the two moduli lines are clearly seen. For comparison generally of strength and elastic properties derived by conventional tensile test procedure and those from compressive tests

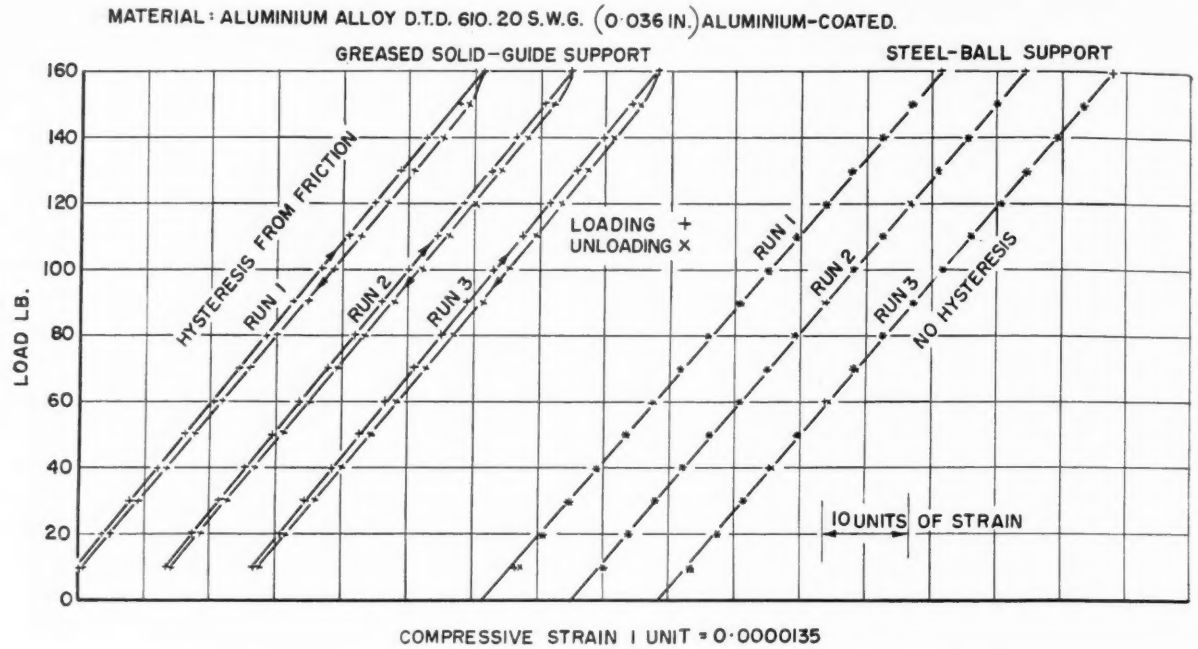

FIGURE 4. Compressive load-strain graphs for consecutive runs within the elastic range.

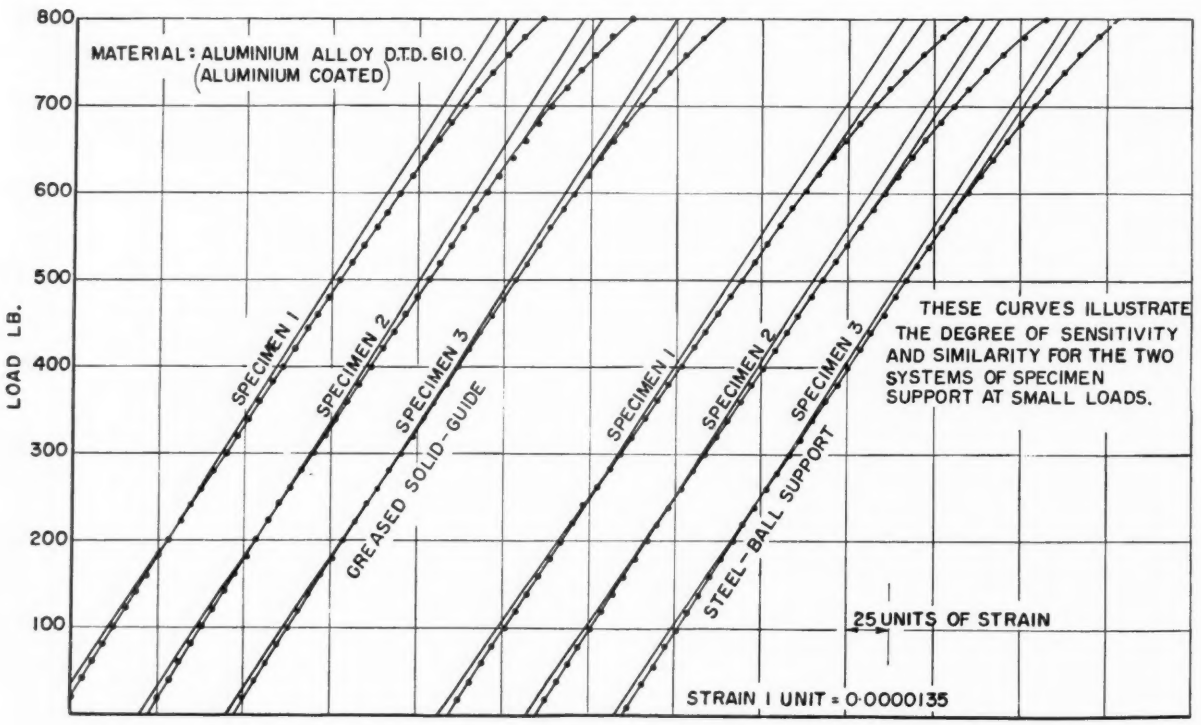

FIGURE 5. Load-strain graphs showing primary and secondary compressive moduli for aluminium-coated aluminium alloy D.T.D. 610.

TABLE I

COMPRESSIVE PROPERTIES OF ALUMINIUM ALLOY D.T.D. 610 (20 S.W.G.) SHEET LATERALLY SUPPORTED BY STEEL-BALLS AND BY GREASED GUIDES

Property Across Direction of Rolling	*Greased Solid-Guide*			*Steel-Ball Support*		
L.P. Tons/in.^{2}	4·8	4·8	4·8	4·9	4·9	4·8
0·1 per cent P.S. „	17·6	17·6	17·4	17·4	17·4	17·7
0·2 per cent P.S. „	19·0	19·0	18·9	18·4	18·4	18·7
0·5 per cent P.S. „	20·1	20·0	20·1	19·9	20·0	20·2
$E_1 \times 10^{-6}$ lb./in.^{2}	10·4	10·5	10·4	10·4	10·4	10·5
$E_2 \times 10^{-6}$ lb./in.^{2}	9·8	9·9	9·8	9·6	9·8	9·8

E_1 = Primary Modulus E_2 = Secondary Modulus

TABLE II

COMPRESSIVE PROPERTIES AND CORRESPONDING TENSILE PROPERTIES OF ALUMINIUM ALLOY D.T.D. 610 (14 S.W.G.) SHEET

Property Across Direction of Rolling	*Tension*			*Compression*		
L.P. Tons/in.^{2}	5·0	5·0	5·0	5·5	5·5	5·4
0·1 per cent P.S. „	25·1	24·8	24·9	25·6	25·5	25·6
0·2 per cent P.S. „	25·9	25·7	25·9	26·4	26·5	26·6
0·5 per cent P.S. „	26·6	26·4	26·6	27·4	27·4	27·7
U.T.S. „	29·2	28·8	28·8	—	—	—
Per cent Elongation on 2 in.	8·0	8·5	8·5	—	—	—
$E_1 \times 10^{-6}$ lb./in.^{2}	10·3	10·4	10·4	10·5	10·6	10·6
$E_2 \times 10^{-6}$ lb./in.^{2}	9·7	9·7	9·9	10·0	10·2	10·2

E_1 = Primary Modulus E_2 = Secondary Modulus

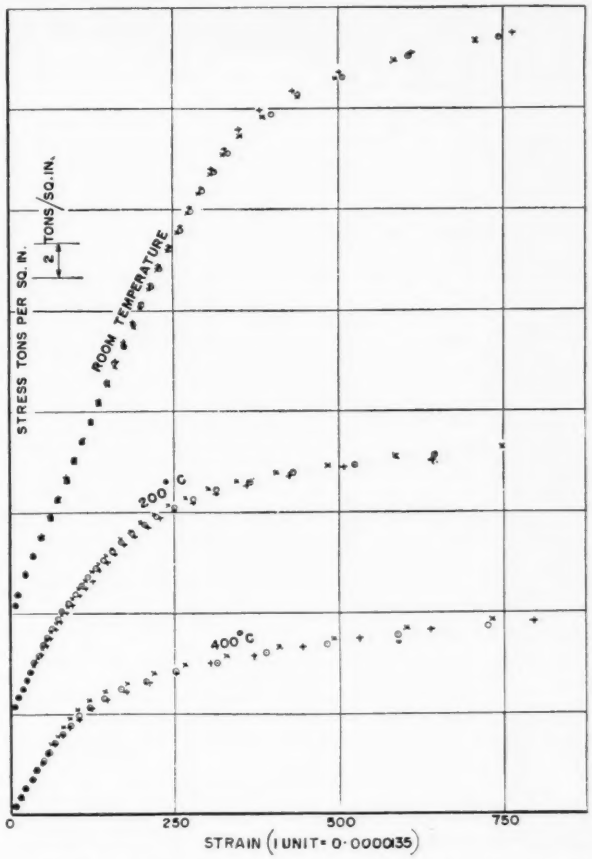

FIGURE 6. Compressive stress-strain graphs for Ti 75A titanium sheet using steel-bell support.

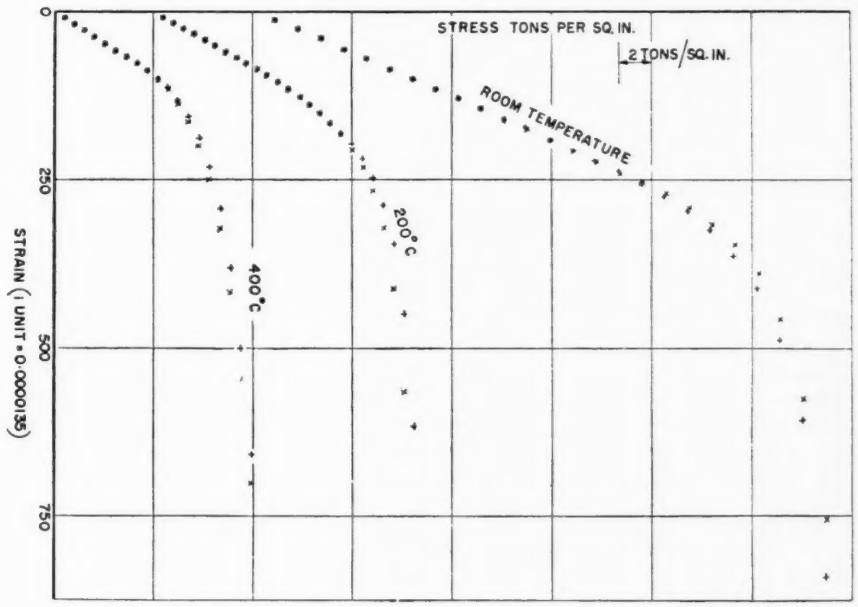

FIGURE 7. Tensile stress-strain graphs for Ti 75A titanium sheet using self-aligning-shackles.

TABLE III

TENSILE AND COMPRESSIVE PROPERTIES OF Ti 75A TITANIUM (16 S.W.G.) SHEET AT ROOM TEMPERATURE, 200°C AND 400°C

Property in the Direction of Rolling	*Test Temperature*														
	Room					200°C					400°C				
	Tension		*Compression*			*Tension*		*Compression*			*Tension*		*Compression*		
L.P. Tons/in.²	6·9	6·9	6·8	6·9	6·9	4·4	4·4	3·7	3·6	3·6	4·4	4·4	3·7	3·7	3·4
0·1 per cent P.S. „	29·6	30·6	29·6	30·1	29·5	13·3	13·0	12·1	11·7	11·8	9·3	9·0	8·2	7·8	7·8
0·2 per cent P.S. „	31·6	32·2	31·6	31·9	31·7	14·5	14·0	13·6	13·2	13·3	10·1	9·9	9·2	8·7	8·8
0·5 per cent P.S. „	33·9	34·4	34·2	34·2	33·9	15·6	15·2	15·3	15·0	15·2	11·6	11·3	10·7	10·5	10·4
U.T.S. „	40·0	40·2	—	—	—	19·4	19·2	—	—	—	14·4	14·5	—	—	—
Per cent Elongation on 2 in.	21·0	19·0	—	—	—	27·0	30·5	—	—	—	17·5	17·5	—	—	—
$E \times 10^{-6}$ lb./in.²	15·7	15·8	15·7	15·7	15·7	12·4	12·3	12·6	12·6	12·7	10·6	10·6	10·7	10·7	10·7

with ball support, *see* Table II. High-strength clad aluminium alloy D.T.D. 546 was selected for these tests because of the considerable total strains required.

To examine the behaviour of the fixture at elevated temperatures up to and including 400°C. and again to compare compressive test values with corresponding tensile test values derived from established tensile test methods, a series of specimens was prepared from a sheet of commercially pure titanium (Ti. 75A). Titanium was chosen because it retains strength at elevated temperature better than aluminium alloys, while having an elastic modulus approximately half that of steel, the other alternative material.

Following the conditions of heating laid down in B.S.S. 1094[7] tests were made on the titanium specimens at room temperature, 200°C. and 400°C. The results from these tests, which are considered satisfactory, are given in Table III and Figs. 6 and 7.

Differential thermal expansion at 400°C. of a metallic specimen and the clamp will be considerably less than the lateral expansion of the specimen when compressed, but no ball indentation of the specimen surface was apparent after testing at elevated temperature.

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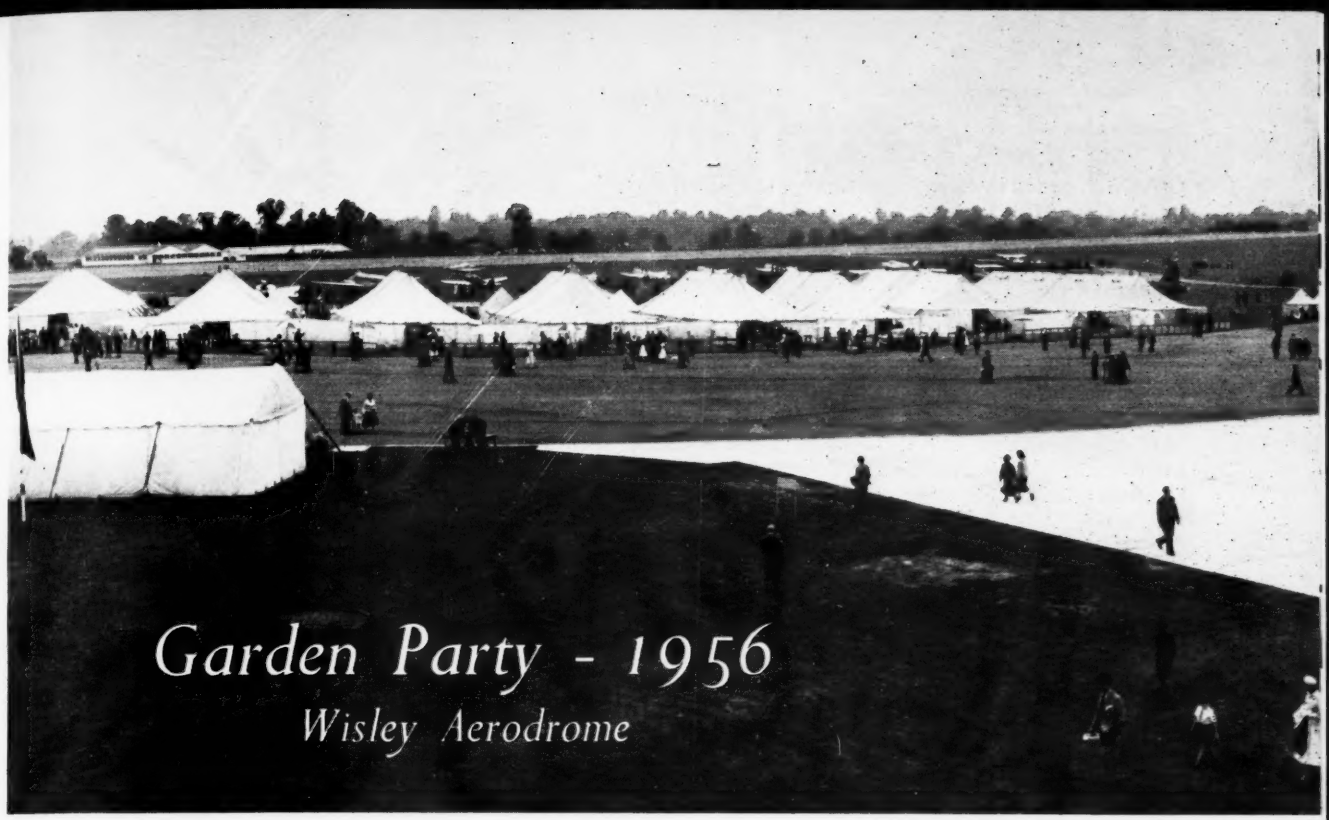


Garden Party - 1956

Wisley Aerodrome

Vickers-Armstrongs (Aircraft) Ltd.

TO HOLD the Garden Party on St. Swithin's Day—15th July—on this of all summers, seemed to be asking for trouble; but St. Swithin was kind, although conditions farther north prevented the arrival of several of the aeroplanes which had been expected to take part in the flying programme. Not too promising in the morning, the weather steadily improved; there was no rain, it was warm and by late afternoon it was a pleasant summer's day.

Wisley, where the Garden Party was held for the first time, by kind permission of the Ministry of Supply and Vickers-Armstrongs (Aircraft) Ltd., is a delightful aerodrome and much of the success of the Garden Party was due to the many services provided by Vickers and the help and enthusiasm of the many members of the Company who assisted with the arrangements. With plenty of garden chairs, much greensward, trees on the skyline and aeroplanes taking off from the grass runway in full view, the atmosphere was pleasantly informal, comparatively quiet and everyone seemed to have an enjoyable afternoon. An ideal Flying Garden Party, in fact.

The Garden Party was attended by some 4,500 members and guests (a number of whom arrived by air) who were received by the President and Mrs. E. T. Jones. During the afternoon a programme of music was played by the Central Band of the Royal Air Force, by permission of the Air Council, and conducted by Squadron Leader F. A. Gale, M.B.E., Director of Music, Royal Air Force.

The Nash Collection of historical aeroplanes, which was acquired by the Society in 1953, was again shown and attracted much attention. Six of the nine aeroplanes in the Collection were housed in two large marquees outside of which was parked the Avro 504K (military version). Another interesting aeroplane which has been added to the Society's collection—a Vickers-Armstrongs Wellington—was on view in the Aircraft Park. The Wellington has been presented recently by Vickers-Armstrongs; it was the last of the 11,461 Wellingtons to be built and was bought back from the Royal Air Force by Vickers.

Also housed in the marquees with the Nash aircraft were a Perspex model of a three foot wind tunnel, with models of a standard aircraft and a guided weapon, kindly lent for the occasion by the Royal Aircraft Establishment, Bedford; a radio-controlled aerobatic model aircraft and its equipment, lent by the Low Speed Aerodynamics Research Association; and a replica of the 1903 Wright Brothers engine which was built by apprentices of the de Havilland Aeronautical Technical School. This engine was lent by the Science Museum to whom it was presented in 1950; it is exact in every detail to the one used by the Wright Brothers for the first heavier-than-air powered flight in 1903 and even has one of the original three cast aluminium crank cases made for the Wrights. The engine was running several times during the afternoon—thanks to the de Havilland Technical School—and made more noise than anything else at the Garden Party!

An interesting flying programme, with some outstanding performances, was provided between 3.00 and 5.30 p.m. The oldest aeroplanes flying were the little Hawker Cygnet, built in 1924, and the D.H. 60 Cirrus Moth built in 1925; the newest was the Edgar Percival E.P.9, which flew for the first time late in December 1955 and made one of its first public appearances at the Garden Party.

In addition the following were among the aeroplanes in the Aircraft Park: D.H. 90A Dragonfly,

G-AEWZ, owned by Silver City Airways Ltd. and flown by Air Cdre. G. J. Powell; D.H. Tiger Moth, G-ANRL, with a new form of aerial spraying equipment developed by Britten-Norman Ltd., owned by Crop Culture (Aerial) Ltd. and flown by J. M. McMahon; two D.H. 82A Tiger Moths, G-AODR and G-ANZZ owned by Norman H. Jones and flown by Mr. Jones and Miss McKeller (these and the Tiger Moth flown by C. Nepean Bishop, which was also owned by Mr. Jones, have been specially stripped for sporting flying); Miles M.65/1A Gemini, G-ACKS, owned by Eagle Aviation Ltd.; Percival Vega Gull, G-AEYC, owned by Central Newbury Car Auctions Ltd. and flown by G. H. and J. L. Rolls.

The Flying Programme was:—

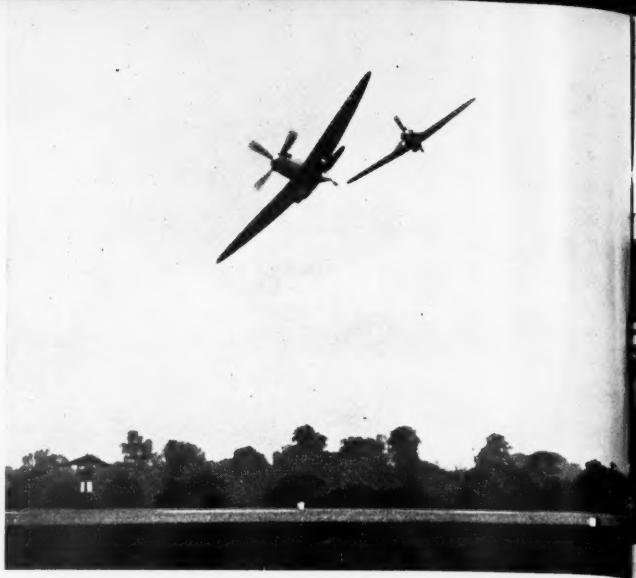
Aircraft	*Pilot*
Fairey Fulmar G-AIBE	Group Capt. Gordon Slade
Fairey Swordfish G-AJVH	Mr. Roy Morris
Edgar Percival E.P.9 G-AOFU	Mr. Edgar Percival
Hawker Cygnet G-EBMB	Mr. Frank Murphy
D.H. 60 (Cirrus) Moth G-EBLV	Mr. C. A. Pike
D.H. Chipmunk, G-AMMA	Mr. D. R. Bevis
D.H. Tiger Moth, G-ANSH	Mr. C. Nepean Bishop
Blackburn B.2 Trainer G-AEBJ	Mr. H. Wood
Whitney Straight G-AFGK	Miss A. A. Windle
Percival Mew Gull G-AEXF	Mr. P. S. Clifford
Fairey Tipsy B G-AISC	Mr. John Dennis
Fairey Tipsy Belfair OO-TIC	Mr. Peder Andersen
Fairey Junior G-AMVP	Mr. John Moreton
Gloster Gladiator G-AMRK	Wing Cdr. R. F. Martin
Vickers-Supermarine Spitfire AB910	Mr. Jeffrey K. Quill
Hawker Hurricane 2C G-AMAU	Mr. W. Bedford
Beechcraft Bonanza 4X-ACI	Mr. S. Lewis
Miles Magister G-AHNW	Mr. D. Ogilvy
Miles Magister G-AJJI	Mr. A. E. Vernon
Miles Magister G-AKKR	Mr. W. H. Bailey
Miles Magister G-AKUA	Miss A. A. Windle
D.H. 94 Moth Minor Coupé G-AFNI	Mr. C. H. Croxson
D.H. Dove (Flying Classroom) G-ALVF	Mr. B. F. Russell
Miles Special Gemini Mk8A Aries G-AKFX	Mr. I. A. Forbes

During the afternoon a lively description of the flying events was broadcast by Mr. Charles Gardner.

The President, Mr. E. T. Jones, C.B., O.B.E., F.R.Ae.S., and the Council wish to put on record their sincere appreciation of the many services rendered in connection with the Garden Party.

They thank the Ministry of Supply and the Directors of Vickers-Armstrongs (Aircraft) Ltd. for permitting it to be held at Wisley Aerodrome. They are particularly indebted to the Directors, especially Mr. G. R. Edwards, President-Elect of the Society, and the Staff of Vickers-Armstrongs (Aircraft) Ltd. for their constant practical help with the organisation and arrangements on the Aerodrome over many weeks.

Mr. G. R. Bryce, Chief Test Pilot, Vickers-Armstrongs (Aircraft) Ltd. was in charge of the flying programme for the day and the President and Council are deeply grateful to him, his Flying Committee and Mr. Harris, Mr. Addicott and Mr. Wheeler, Air Traffic Control Officer and his staff.



Flight

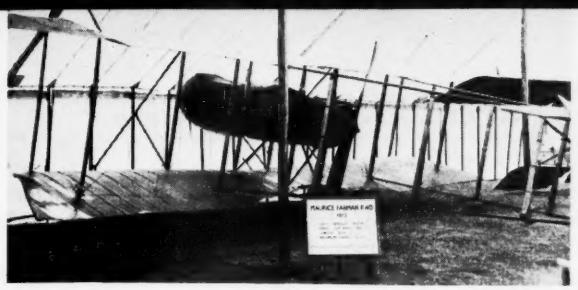
One of the highlights of the flying programme—a mock battle between the Vickers Supermarine Spitfire, flown by J. K. Quill, and the Hawker Hurricane, flown by W. Bedford.

They also wish to thank Mr. R. Edmonds, Manager, Works Administration, Weybridge Works, and Mr. R. Darch, and their staff who made all the arrangements on the aerodrome on behalf of Vickers.

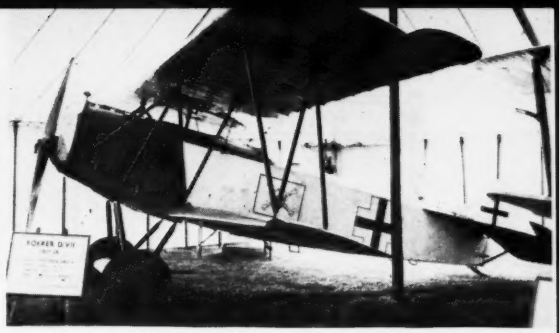
The refurbishing of the aircraft of the Nash Collection for the Garden Party was done on behalf of the Society by apprentices of Vickers-Armstrongs, Weybridge, under the direction of Mr. E. G. Barber.

Van Hallan

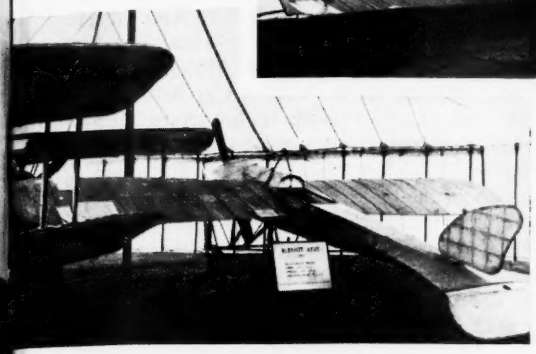
Sir Frederick and Lady Handley Page being received by the President and Mrs. E. T. Jones.



↑ Maurice Farman, 1913



Fokker D. VII, 1917
(*top right*)



← Bleriot XXVII, 1910

S.E. 5A, 1918 →

← Caudron G.III, 1912

Sopwith Camel, 1917 →

← Avro 504 K (Military), 1914

Vickers-Armstrongs →
Wellington Mk. X

The Society's Collection of Historical Aircraft.
(Photographs by Vickers-Armstrongs)

and apprentices also mounted guard in the marquees over the aircraft; their work is greatly appreciated.

Thanks are due also to Mr. Charles Gardner for his broadcast commentary; to the Public Relations Staff; to Dr. A. H. Lankaster and Dr. R. Wilson of the Vickers-Armstrongs (Aircraft) Ltd. Weybridge Works Medical Staff and volunteers from the Works First Aid Group who were on duty during the day; and the Works Police and others who contributed so much to the smooth working of the arrangements generally.

The President and Council also thank the Air Council for permitting the Central Band of the Royal Air Force to play during the afternoon.

As always, much of the success of the Garden Party depended on the pilots, ground crews, private owners and all those who so willingly provided, flew and serviced the aircraft; their assistance was deeply appreciated. In addition to the pilots and private owners the President and Council are greatly indebted to the following for making the aircraft and static exhibits available: Avions Fairey S.A., Blackburn and General Aircraft Ltd., Central Newbury Car Auctions Ltd., the College of Aeronautics, The de Havilland Aircraft Co. Ltd., Derby Aviation Ltd. (Elstree Flying Club), Edgar Percival Aircraft Ltd., the Fairey Aviation Co. Ltd., the Gloster Aircraft Co. Ltd., Hawker Aircraft Ltd., the Low Speed Aerodynamics Research Association, the Ministry of Supply, the Ministry of Transport and Civil Aviation, the Royal Aircraft Establishment, Silver City Airways Ltd. and Vickers-Armstrongs (Aircraft) Ltd. Supermarine Works.

The President and Council wish to thank Shell-Mex and B.P. Ltd. for providing the equipment for, and the supply of, aviation fuel and oil; the Service Department, de Havilland Engine Co. Ltd.; and the Service Department, Aviation Division, Dunlop Rubber Co. Ltd., for services on the aerodrome, and the British Aviation Insurance Co. Ltd.

The Aeroplane

Wisley *en fête.*

They also thank sincerely the members of the de Havilland Technical School and R.A.F. Apprentices from Halton who helped on the aerodrome, and the Surrey Constabulary, the Automobile Association, the Vickers Police, and the British Legion Car Attendants, who ensured remarkably smooth traffic arrangements.

The catering arrangements were by Gunter & Co. Ltd.

The success of the Society's Garden Parties depends on much voluntary assistance of every kind; to name individually all those who contributed to the detailed organisation and many arrangements required is impossible, but the President, the Council, the Secretary and the Staff appreciate greatly the willing and enthusiastic assistance which they received from everyone concerned.

The Society's Collection of Historical Aircraft

Since the Nash Collection of Veteran Aircraft, which was acquired by the Society in 1953, was shown at the 1954 Garden Party (and described in the September 1954 JOURNAL), additional information has been added to the history of some of the aeroplanes.

Mr. A. J. Jackson of " Air Britain " has corrected the information on the CAUDRON G.III. It was originally flown to this country by Mr. Ken Waller early in 1936 when it carried the Belgian registration OO-ELA. It was registered in the British register of Civil Aviation in January 1937 as G-AETA, owner Mr. Waller, and the manufacturer's serial number was given as 7487, but it has never carried these letters and remains OO-ELA (on the wings).

When the Garden Party Programme was prepared this year it had been suggested by Mr. A. J. Jackson that the AVRO 504 K (Military type) was registered first in 1930 as G-ABAA and that it was built from spares, but according to Mr. Nash's information it was owned by several firms between 1922 and 1938 when it was flown from Scotland by a Flight Lieut. Birch to join the Nash Collection. Since the Garden Party Mr. Jackson has written to say that from his files, which are probably unique, no 1922 Avro 504 Ks were on the British Register in 1938 and there is no record of anyone called Birch on the Register in 1936-38. As G-ABAA did not appear until 1931 it is obviously not the Nash Avro 504 K. It seems likely that it may have been built from spares, as Mr. P. G. Cooksley has pointed out that the wheels are more probably from an Avro 504 N.

It has now been established, by both Mr. A. J. Jackson and Mr. P. G. Cooksley that the S.E.5A was originally G-EBIC, one of Major J. Savage's skywriting fleet from Hendon. Although registered in 1923, its manufacturer's serial 687/2404 suggests to Mr. Jackson that it was built by Armstrong Whitworth and, as no R.A.F. serial number was given on its original certificate of civil registration, it was probably a new aircraft ex works stock when Major Savage bought it. It was sold to a firm of scrap dealers in Hounslow in 1938 and from there joined the Nash Collection. It is known to be a hybrid, the wings having been taken from another S.E.5A.

In 1954 the SOPWITH CAMEL was identified by Mr. Grenville Manton as one he bought—and flew—in the early 1920's from the Aircraft Disposal Company at Waddon. It was built by Boulton Paul and its log book showed that it had done some test flying. Mr. Manton sold it to someone who towed it from Tring, Herts, to North Wales behind a small Fiat car. Mr. P. G. Cooksley believes that it was registered then as G-EBER. Mr. Frank Yeoman, of West Hartlepool, identified the Camel last year as F.6314 which came back from Wales in the mid-thirties and was owned by a Mr. D. C. Mason in 1936. The Camel was found in a barn in Hornchurch, Essex, about that time by Mr. Nash, who has confirmed a suggestion made by Mr. A. L. Eggleton, A.R.Ae.S., that this Camel was one of three or four which were modified in 1917 with two Lewis guns and a wider opening in the centre section as an experiment for night fighting. Known as the Camel F1/3, it was, according to Mr. Eggleton, used by No. 44 Squadron R.F.C. at Hainault Farm, Essex, after it left Martlesham. One of the puzzling things about the Nash Camel was what appears to be the markings of the Fourth Lafayette Escadrille on the fuselage; Mr. B. T. Gibbins, who has some extremely interesting photographs of Camels of No. 44 Squadron R.F.C., including one of three F1/3s and another of "A", "B" and "C" Flight emblems, has suggested that the supposed Lafayette emblem, which is not quite correct as shown on the Nash Camel, is really the "C" Flight emblem of No. 44 Squadron.

The Society is most grateful to all those who have added to the information on the Nash Aircraft and hopes that anyone who can, will continue to add to the history of each aircraft.

During the past two years several of the aircraft in the Nash Collection have been lent for various purposes. The Avro 504 K was lent for ground shots in the film " Reach for the Sky "; the Bleriot XXVII was lent to B.O.A.C. in 1954 for its Fourth Annual Festival; the Bleriot, Avro 504 K, Fokker D.VII, S.E.5A and Camel were lent to R.A.F. Station, Lichfield, Staffs, for its 1955 Battle of Britain Display; and the S.E.5A was borrowed by No. 56 Squadron, R.A.F., Waterbeach, on the occasion of the presentation of the Squadron Standard by H.R.H. the Duchess of Kent on 27th April 1956.

Just before the Garden Party Vickers-Armstrongs (Aircraft) Ltd. presented to the Society for its historical collection a Wellington Mk. X, M.F. 628. Last of the 11,461 Wellingtons to be built, it served with No. 1 School of Air Navigation, Hullavington, and was bought back from the R.A.F. by Vickers.

TECHNICAL NOTES

Contributions to this Section of the JOURNAL *will be eligible for Journal Premium Awards and will normally be published within three months of being received.*

The Analysis of Transient Vibration Data

by

J. P. ELLINGTON AND H. McCALLION

(*Departments of Civil and Mechanical Engineering, University of Nottingham*)

A NEW PROOF is given of a method whereby records of the transient vibrations of linear systems can be analysed to give the damping factor and frequency of each mode of vibration associated with the motion. The method is applicable to acceleration, velocity or displacement records, and as the amplitude of each mode can be found, by using a suitable number of pickups, the normal modes of continuous systems may also be determined. Obvious applications lie in the analysis of flight flutter test data, and of the transient responses of servo-mechanisms.

INTRODUCTION

The importance and desirability of making flight flutter tests of high speed aircraft in conjunction with theoretical calculations can no longer be denied, and the obtaining of vibration records from aircraft in flight and their subsequent analysis is rapidly becoming standard practice[1, 2]. However, the value of these tests does depend upon the correct interpretation of the data obtained, and in many cases this interpretation is far from easy[3].

The most important factor to be deduced from these tests is the damping factor of the various possible modes of vibration at gradually increasing air speeds, extrapolation of the damping factor against air speed curve to a zero damping factor giving a critical flutter speed. No great difficulty is experienced in analysing results from systems having a well defined fundamental frequency, as the transient vibration eventually becomes a sinusoidal decay curve. This simple state does not always obtain in aircraft, there being possible a large number of coupled modes, and it is not impossible to find two or more modes whose frequencies lie so close together that only a complex beating is observed, and the standard analysis of the decay record becomes virtually meaningless.

The purpose of the present note then is to restate a method of determining from a decay record the damping factors, frequencies and amplitudes of all the modes involved in a transient vibration. The final result given below was first quoted by Sir J. J. Thomson[4] in connection with the determination of X-ray absorption coefficients, but although he did point out the more general application his work seems to have remained unnoticed. In view of the pressing necessity of an adequate means of analysing vibration records the authors feel that the method should be brought to notice, and a new proof of the result, more palatable to engineers, is given below.

DERIVATION

Taking a system composed of masses and linear restoring elements with viscous damping resistances, having $n/2$ degrees of freedom and performing small motions about an equilibrium position, then it is known from the theory of linear differential equations that the frequency equation of the system will have n roots p_i, and that the motion of some chosen point will be given by

$$y = A_1 \exp(p_1 t) + A_2 \exp(p_2 t) + \ldots . A_n \exp(p_n t) \quad (1)$$

The constants A_i depend on the initial conditions, while the exponents p_i may be real, imaginary or complex, it being assumed that no two roots are equal.

Suppose now that a vibration record has been obtained, and that a total of $2n$ values of y have been measured at equal time intervals T, at $t=0$, y being y_0, at $t=T$, y being y_1, etc., then from equation (1),

$$\begin{aligned} y_0 &= A_1 + A_2 + \ldots \ldots \ldots A_n \\ y_1 &= A_1 Z_1 + A_2 Z_2 + \ldots \ldots A_n Z_n \\ y_2 &= A_1 Z_1^2 + A_2 Z_2^2 + \ldots \ldots A_n Z_n^2 \end{aligned} \quad . \quad . \quad . \quad (2)$$

or

$$y_k = A_1 Z_1^k + A_2 Z_2^k + \ldots \ldots A_n Z_n^k \; (k = 0, 1, 2 \ldots 2n-1)$$

where

$$Z_1 = \exp(p_1 T),\ Z_2 = \exp(p_2 T), \text{ etc.} \quad . \quad . \quad . \quad (3)$$

Equations (2) represent a set of $2n$ linear simultaneous equations in the n unknowns A_i, and thus there are twice as many equations as there are unknowns. Hence for these equations to be consistent, or not self-contradictory, there must be n eliminants equal to zero. Eliminating A_1 to A_n from the first $(n+1)$ equations gives the determinant D_1,

$$D_1 = 0 = \begin{vmatrix} y_0 & 1 & 1 \ldots \\ y_1 & Z_1 & Z_2 \ldots \\ \ldots & \ldots & \ldots \\ y_n & Z_1^n & Z_2^n \ldots \end{vmatrix}$$

Again, eliminating the A_i's from the $(n+1)$ equations beginning with y_1 gives,

$$D_2 = 0 = \begin{vmatrix} y_1 & Z_1 & Z_2 \ldots \\ y_2 & Z_1^2 & Z_2^2 \ldots \\ \ldots & \ldots & \ldots \\ y_{n+1} & Z_1^{n+1} & Z_2^{n+1} \ldots \end{vmatrix} =$$

Received 26th June 1956

$$= \begin{vmatrix} y_1 & 1 & 1 \ldots \\ y_2 & Z_1 & Z_2 \ldots \\ \ldots & \ldots & \ldots \\ y_{n+1} & Z_1^n & Z_2^n \ldots \end{vmatrix}$$

and generally,

$$D_j = 0 = \begin{vmatrix} y_{j-1} & 1 & 1 \ldots \\ y_j & Z_1 & Z_2 \ldots \\ \ldots & \ldots & \ldots \\ y_{j+n-1} & Z_1^n & Z_2^n \ldots \end{vmatrix}$$

Now multiply determinant D_1 by a_0, determinant D_2 by a_1, etc., the a's being as yet undefined, and then take the sum to give,

$$0 = \begin{vmatrix} (a_0y_0 + a_1y_1 + \ldots) & 1 & 1 \ldots \\ (a_1y_1 + a_1y_2 + \ldots) & Z_1 & Z_2 \ldots \\ \ldots & \ldots & \ldots \\ (a_0y_n + a_1y_{n+1} + \ldots) & Z_1^n & Z_2^n \ldots \end{vmatrix} \quad . \quad (4)$$

The a's are now to be chosen so that, if possible, the elements of the first column of equation (4) each become an integral power of some function, or quantity λ.

Then

$$\begin{aligned} a_0y_0 + a_1y_1 + \ldots &= \lambda^0 \\ a_0y_1 + a_1y_2 + \ldots &= \lambda \\ \ldots & \\ a_0y_n + a_1y_{n+1} \ldots &= \lambda^n \end{aligned} \quad . \quad (5)$$

There are thus $(n+1)$ equations for the n unknown a's, so once again the eliminant of the equations must be zero, and

$$0 = \begin{vmatrix} 1 & y_0 & y_1 \ldots & y_{n-1} \\ \lambda & y_1 & y_2 \ldots & y_n \\ \lambda^2 & y_2 & y_3 \ldots & y_{n+1} \\ \ldots & \ldots & \ldots & \ldots \\ \lambda^n & y_n & y_{n+1} \ldots & y_{2n-1} \end{vmatrix} \quad . \quad (6)$$

Returning now to equation (4) and substituting from equation (5).

$$0 = \begin{vmatrix} 1 & 1 & 1 \ldots \\ \lambda & Z_1 & Z_2 \ldots \\ \lambda^2 & Z_1^2 & Z_2^2 \ldots \\ \ldots & \ldots & \ldots \\ \lambda^n & Z_1^n & Z_2^n \ldots \end{vmatrix} \quad . \quad (7)$$

Equation (7) is now an alternant determinant[5], and is a polynomial of degree n in λ. This determinant can be evaluated easily, but for the purpose of this discussion it is sufficient to note that, say, $(\lambda - Z_1)$ is a factor because if $\lambda = Z_1$ then two columns are equal and the determinant is zero. $(\lambda - Z_2)$, $(\lambda - Z_3)$, etc., are also seen to be factors, and in a similar manner $(Z_1 - Z_2)$, $(Z_1 - Z_3)$, $(Z_2 - Z_3)$, etc. are also factors.

Now, under that assumption that none of the roots of the frequency equation are equal, none of the Z are equal and thus equation (7) is zero only if the factors $(\lambda - Z_1)$, $(\lambda - Z_2)$, etc. are zero and thus, there are n possible values of λ,

$$\lambda_m = Z_m \quad . \quad . \quad . \quad . \quad . \quad (8)$$

In view of this, equation (6) now becomes a polynomial of degree n in Z and is a characteristic equation having real coefficients and yielding the required exponents.

$$0 = \begin{vmatrix} 1 & y_0 & y_1 \ldots & y_{n-1} \\ Z & y_1 & y_2 \ldots & y_n \\ Z^2 & y_2 & y_3 \ldots & y_{n+1} \\ \ldots & \ldots & \ldots & \ldots \\ Z^n & y_n & y_{n+1} \ldots & y_{2n-1} \end{vmatrix} \quad . \quad . \quad (9)$$

If the system under examination was performing damped oscillations then the roots p_i in equation (1) would occur in conjugate complex pairs, as would the corresponding values of Z_i from equation (9). The roots p would be of the form $c + i\omega$, while Z would be of the form $a + ib$, thus from equation (3):

$$\begin{aligned} \exp(c + i\omega)\, T &= a + ib \\ &= \sqrt{(a^2 + b^2)} \exp(i\theta) \end{aligned} \quad . \quad (10)$$

where $\theta = \arctan(b/a)$.

Equating imaginary and real parts in equation (10), the natural circular frequency ω (not to be confused with the resonant frequency) is given by,

$$\omega = \theta/T = (1/T) \arctan(b/a) \quad . \quad . \quad (11)$$

and the logarithmic decrement defined by $\delta = 2\pi c/\omega$ is

$$\delta = \pi \log_e (a^2 + b^2)/\arctan(b/a) \quad . \quad . \quad (12)$$

The amplitudes A_i of the various modes can then be found from equation (2), and for a continuous structure, if vibration records are taken at several points, knowledge of the relative amplitudes will allow normal modes to be constructed.

SUMMARY

By measuring a transient vibration record and then evaluating a characteristic equation the damping factors and frequencies of vibration can readily be evaluated.

ACKNOWLEDGMENT

The authors would like to thank Mr. M. O. W. Wolfe, of the Structures Department, Royal Aircraft Establishment, Farnborough, for suggesting to one of them (H. McCallion), that the problem was a pressing one for the Aircraft Industry, and that apparently there was no solution available.

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The Effect of Stress Concentrations on the Fatigue Resistance of a Duralumin Type Aluminium Alloy

by

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DURING the past hundred years much data on the fatigue behaviour of a wide range of materials has been accumulated and it is now well known, as a result of service failures and laboratory tests, that stress concentrators whether mechanically formed or inherent in the material, can cause serious reductions in endurance.

The work described in this note forms part of a project being conducted at the Aeronautical Research Laboratories, Melbourne, Australia on the effect of stress concentrations on the fatigue properties of materials. The primary aim of the project is to establish a series of fatigue curves for different materials under a wide range of theoretical stress concentration factors and to attempt to find a basis on which to assess the notch sensitivity of different materials. The first investigation was carried out on 24S-T aluminium alloy[1] and tests on two additional aluminium alloys, annealed copper and an alloy steel are in progress.

MATERIAL AND TESTS

The 24S aluminium alloy, on which the tests were made, was received in the form of bars $\frac{5}{8}$ in. in diameter and six feet long and was in the RT condition, *i.e.* solution treated, aged and cold rolled. The average chemical composition of the material, as found by the analysis of a composite sample, is given in Table I. The specification figures, with which the material complied, are also given.

Rotating cantilever fatigue specimens, of the form shown in Fig. 1, and tensile control specimens were taken from each bar. These were rough formed to 0·020 in. oversize and then given a heat treatment consisting of solution treatment at 490°C (914°F) for 30 minutes followed by quenching in cold water and ageing for 16 hours at 40°C (104°F).

The unnotched fatigue specimens were finished by diamond turning, the depth of finishing cut being 0·0005 in. and feed 0·001 in. per revolution, while the notches were machined by a single plunge cut of a form tool. No further machining or polishing operations were carried out after the lathe operations just described. The notch radii and the diameter of the test section of all specimens were measured using a toolmakers' microscope.

Tensile tests were carried out in a 60,000 lb. capacity universal testing machine and data obtained enabling 0·1 per cent and 0·2 per cent proof stresses, ultimate tensile strength, reduction of area and elongation on a 2·00 in. gauge length to be determined. Brinell type hardness tests were made on the ends of about 30 per cent of the specimens tested using a Vickers Hardness Testing Machine fitted with a 2 mm. ball and employing a 40 kg. load.

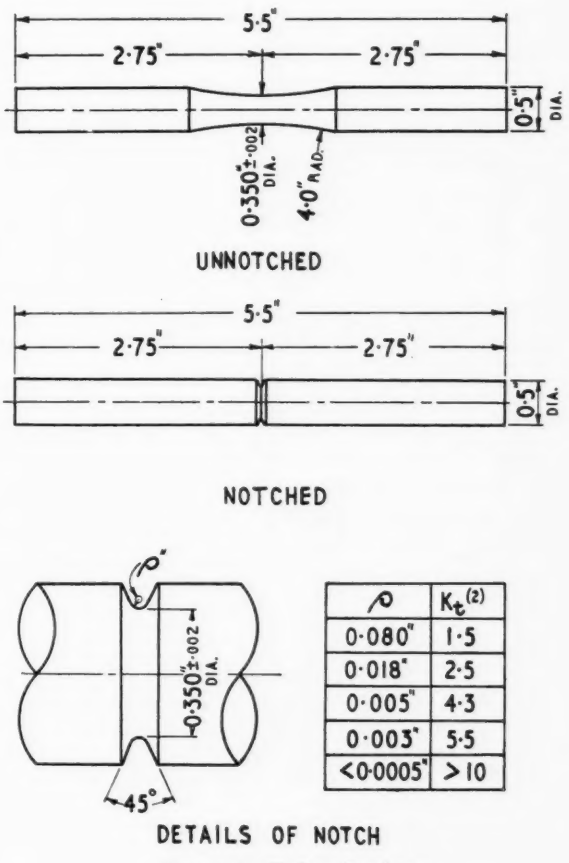
All the fatigue tests were made in the A.R.L. single point loading rotating cantilever fatigue machines[3] which

Received 15th May 1956

TABLE I

CHEMICAL COMPOSITION OF MATERIAL

Element	*Specification S.A.–(E) 2D·649 per cent*	*Composite Sample per cent*
Copper	3·8–4·9	4·49
Magnesium	1·2–1·8	1·42
Manganese	0·3–0·9	0·57
Iron	⩾0·5	0·35
Silicon	⩾0·5	0·20
Zinc	⩾0·1	0·11
Nickel	⩾0·1	—
Titanium	—	Trace
Others	Total ⩾0·15	—
Aluminium	Remainder	Remainder



ρ	K_t (2)
0·080"	1·5
0·018"	2·5
0·005"	4·3
0·003"	5·5
<0·0005"	>10

FIGURE 1. Fatigue Specimens.

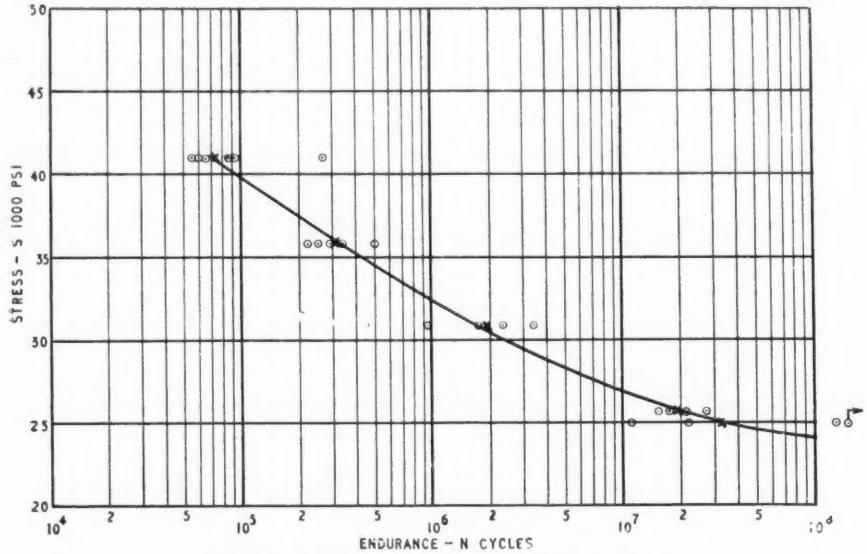


FIGURE 2. Fatigue test results—unnotched specimens.

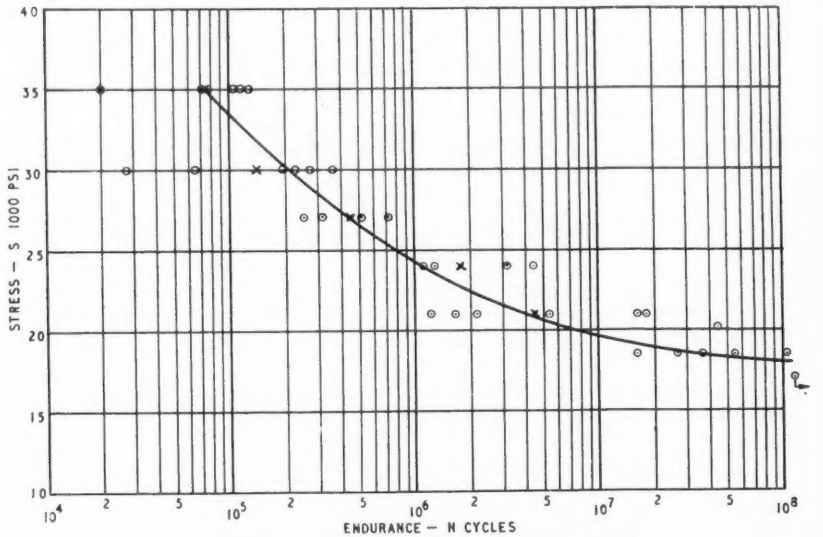


FIGURE 3. Fatigue test results—0·080 in. ρ notch.

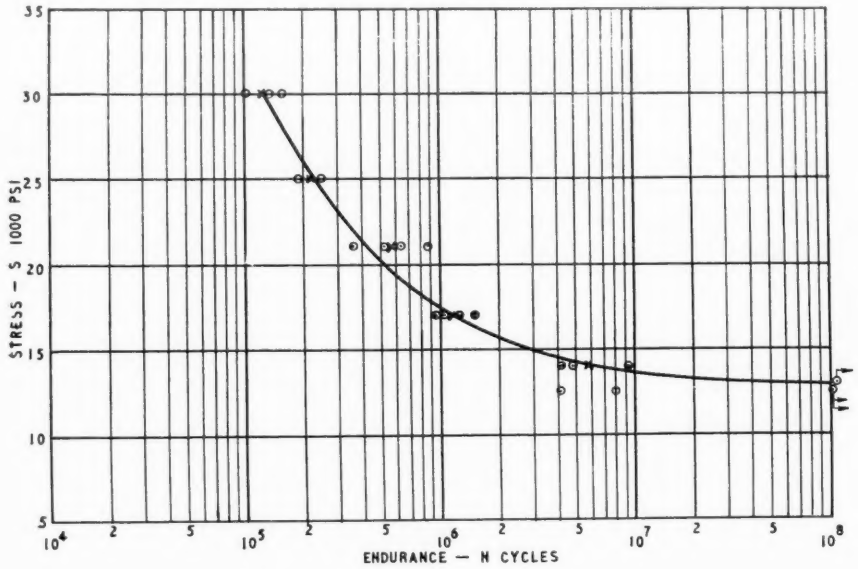


FIGURE 4. Fatigue test results—0·018 in. ρ notch.

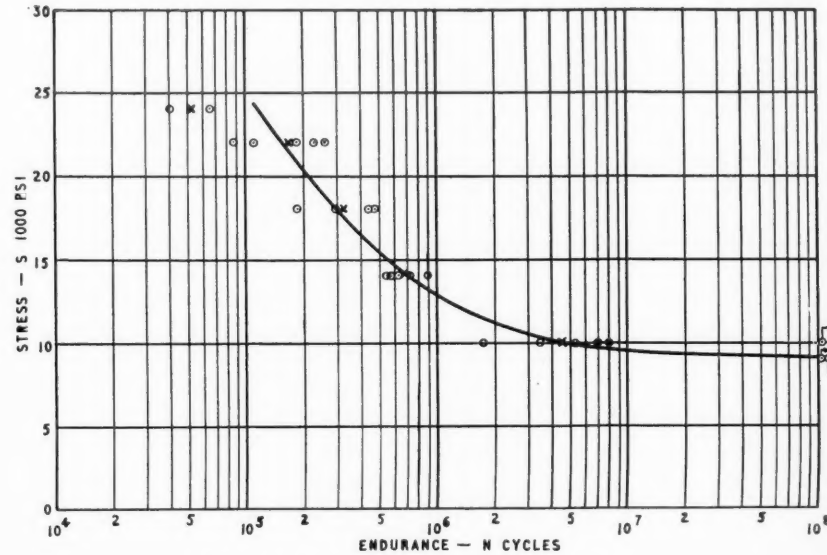


FIGURE 5. Fatigue test results—0·005 in. ρ notch.

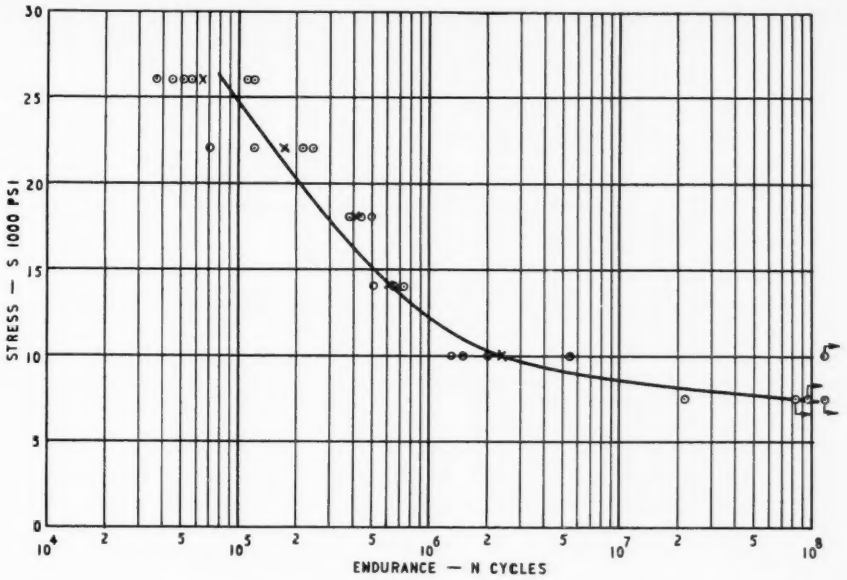


FIGURE 6. Fatigue test results—0·003 in. ρ notch.

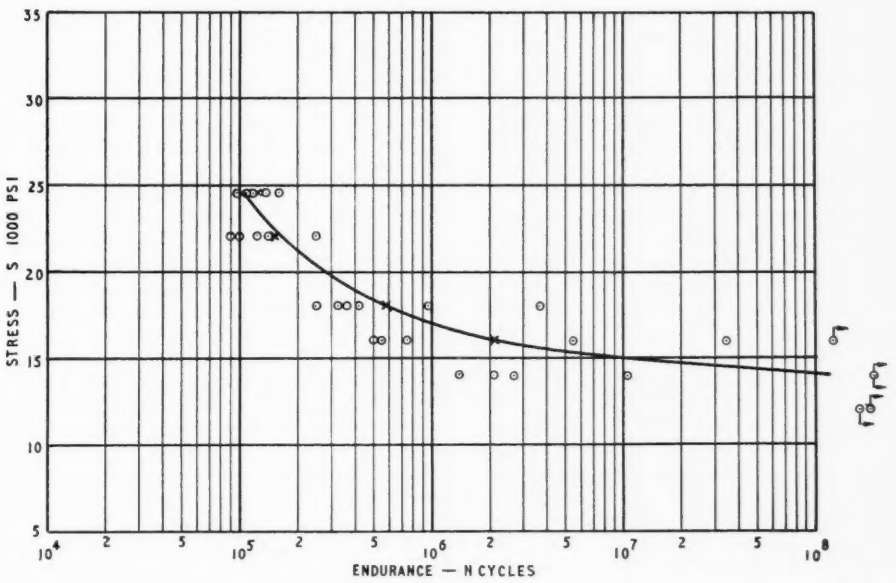


FIGURE 7. Fatigue test results—<0·0005 in. ρ notch.

TABLE II

TENSILE PROPERTIES OF MATERIAL

Property	*Range*		*Average*	*Specification S.A.A.—(E) 2D·649 (Min.)*
	Min.	*Max.*		
0·1 per cent Proof Stress (p.s.i.)	37,200	42,900	39,900	38,000
0·2 per cent Proof Stress (p.s.i.)	39,000	44,800	41,900	40,000
Ultimate Tensile Stress (p.s.i.)	65,000	69,700	67,100	63,000
Reduction of area (per cent)	23·7	39·9	34·4	—
Elongation on 2 in. (per cent)	19·0	27·0	22·5	12
Hardness	126	132	129	—

operate at 12,000 cycles per minute. Approximately 30 specimens were used to determine each fatigue curve, at least four specimens being tested at each stress level. All the stresses quoted are nominal stresses calculated from the beam formula, where stress equals the bending moment divided by the section modulus.

RESULTS OF TESTS

The results of tensile tests are given in Table II while the fatigue test results are shown in the S-log N diagrams of Figs. 2-7, on which are drawn the logarithmic mean curves. Values of strength reduction factor, K_f*, for each notch were calculated from the mean curves at a number

* $K_f = \left.\dfrac{\text{fatigue strength of unnotched specimens}}{\text{fatigue strength of notched specimens}}\right\}$ at the same endurance.

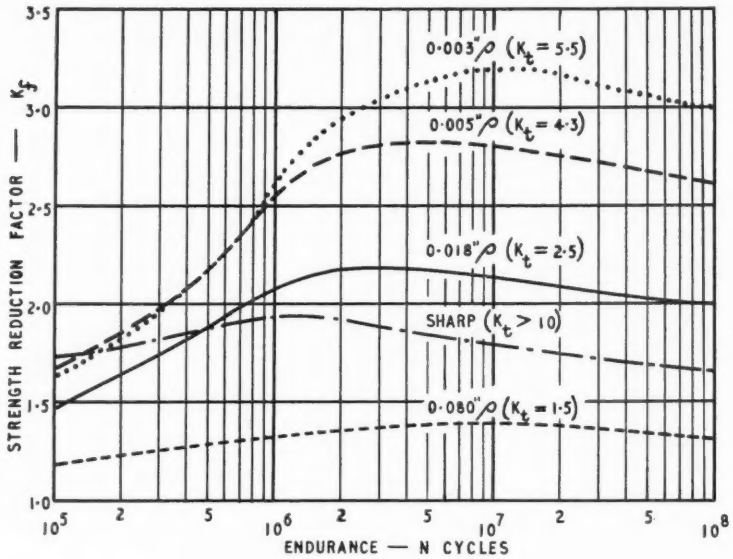


FIGURE 8. Relation betwen K_f and N.

of endurances, and curves of K_f against log N are shown in Fig. 8.

DISCUSSION OF RESULTS

The curves of Fig. 8 show clearly that the value of K_f for any particular notch is not a constant, but depends on the endurance at which it is measured. Also, that the values of K_f for a given notch appear to reach a maximum at an endurance of between about 10^6 and 10^7 cycles, the actual endurance value seemingly being dependent, to a first approximation, on the magnitude of the stress concentration. Table III indicates the maximum strength reduction factor (K_{fm}) due to each notch and its percentage of the theoretical stress concentration factor.

Reference to Fig. 8 and Table III indicates that the maximum strength reduction is not caused by the sharp notch, which has the greatest theoretical stress concentration factor, but by a notch of about 0·003 in. root radius. It may also be seen from Fig. 8 that at endurances in excess of 5×10^5 cycles, all the notches tested with the exception of the 0·080 in. radius notch, cause a greater strength reduction than the sharp notch. The relationship between K_t and K_{fm} on the one hand and K_{fm}/K_t on the other is indicated in Fig. 9. This shows that a linear relationship exists between K_{fm}/K_t and K_t and it follows that K_{fm} and K_t are related by the expression:

$$K_{fm} = K_t\ (1{\cdot}09 - 0{\cdot}09K_t)$$

By differentiation, the maximum possible value of K_{fm} can be shown to be 3·2, the corresponding value of K_t being 5·8. In other words, the maximum strength reduction for 24S-T aluminium alloy under the reported test conditions, approximately 70 per cent, would be due to a stress concentrator of $K_t = 5{\cdot}8$.

These results suggest that for any given material, there may be a critical value of stress concentration which causes the maximum strength reduction under fatigue loading and it could thus be expected that notches having K_t values in excess of the critical value will in fact give increased fatigue properties. Although there is little systematic fatigue data on the effects of a range of notches of known K_t on the fatigue behaviour of any particular material, there is other evidence that very sharp notches (having a high value of K_t) do not cause as severe a reduction in strength as might be expected. Phillips and Heywood[4] for example, who carried out direct stress fatigue tests on an 0·1 per cent carbon steel, have reported that a 55° V-notch of 0·002 in. root radius ($K_t = 14$) and one of 0·025 in. root radius ($K_t = 4{\cdot}4$) gave exactly the same fatigue curves.

An expression of the above form would enable the maximum strength reduction factor for a given notch to be calculated if its K_t value be known. If it can be shown that a similar expression holds for other materials and that the relation between K_{fm}/K_t and K_t is linear, all that is necessary to obtain the maximum strength reduction due to any notch of known K_t, is the S-log N curve for one standard notch, preferably of K_t about 10, and the

TABLE III

MAXIMUM STRENGTH REDUCTION FACTORS

K_t	*Maximum K_f (K_{fm}) at cycles indicated*		$\frac{K_{fm}}{K_t}$ per cent
1	1	—	100
1·5	1·4	10×10^6	93
2·5	2·2	3×10^6	88
4·3	2·8	5×10^6	65
5·5	3·2	9×10^6	58
>10	1·9	$1{\cdot}5 \times 10^6$	19

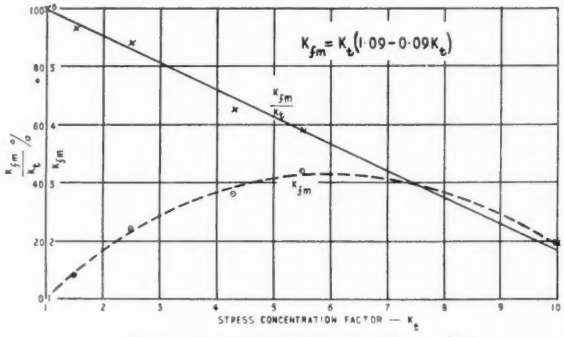


FIGURE 9. Relation between K_{fm} and K_t

S-log N curve for the unnotched material. One might expect the values of the constants in this expression to be dependent to some extent on the fatigue test conditions whether bending, reversed axial loading, torsion, etc., and they may also be influenced by changes in grain size, chemical composition, metallurgical conditions and physical dimensions of the stress concentrator, but the influence of these variables can only be determined by experiment.

CONCLUSIONS

The value of the strength reduction factor, K_f, for a particular notch is dependent on the endurance at which it is measured, but appears to reach a maximum at between 10^6 and 10^7 cycles.

The greatest reduction in fatigue strength, *i.e.* the maximum possible value of K_f, is not caused by the sharpest notch. For this alloy K_t and K_{fm} are related by the expression

$$K_{fm} = K_t\,(1{\cdot}09 - 0{\cdot}09K_t)$$

where K_{fm} is the maximum strength reduction factor due to a notch of theoretical stress concentration factor K_t. From this expression it follows that the maximum strength reduction ($K_f = 3{\cdot}2$) will be caused by a notch of $K_t = 5{\cdot}8$.

ACKNOWLEDGMENT

The author acknowledges the permission of the Chief Scientist, Department of Supply, Australia, to publish this Note.

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A Note on the Checking of Contractants

by

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A SIMPLE means of checking contractants has been devised which is considered essential to a computor.

INTRODUCTION

In a recent paper[1] Macmillan describes the method of contractants as applied to the evaluation of determinants. The method is essentially based on the extensional identity

$$\begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix} = \frac{1}{b_2} \begin{vmatrix} \begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix} & \begin{vmatrix} b_1 & c_1 \\ b_2 & c_2 \end{vmatrix} \\ \begin{vmatrix} a_2 & b_2 \\ a_3 & b_3 \end{vmatrix} & \begin{vmatrix} b_2 & c_2 \\ b_3 & c_3 \end{vmatrix} \end{vmatrix}$$

which, in the notation of contractants, is written as

$$= \begin{vmatrix} \begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix} & & \begin{vmatrix} b_1 & c_1 \\ b_2 & c_2 \end{vmatrix} \\ & b_2 & \\ \begin{vmatrix} a_2 & b_2 \\ a_3 & b_3 \end{vmatrix} & & \begin{vmatrix} b_2 & c_2 \\ b_3 & c_3 \end{vmatrix} \end{vmatrix}$$

Now, any determinant of order n may be expressed as a determinant of order $n-1$, all of whose elements are third order determinants[2]. This process is now repeated $(n-2)$ times until the value of the original determinant is obtained.

The advantage of the method of contractants as against that of, say, pivotal condensation, is the decidedly simpler programme for a digital computor. However, the method, as given, is not complete without some suitable checking facility. This is now given.

Received 5th June 1956

THE CHECK

Instead of considering A alone as given by

$$A = \begin{vmatrix} a_1 & b_1 & c_1 & \cdot & \cdot & \cdot & \cdot & q_1 \\ a_2 & b_2 & c_2 & \cdot & \cdot & \cdot & \cdot & q_2 \\ a_3 & b_3 & c_3 & \cdot & \cdot & \cdot & \cdot & q_3 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ a_n & b_n & c_n & \cdot & \cdot & \cdot & \cdot & q_n \end{vmatrix}$$

it is desirable to treat also B as given by*

$$B = \begin{vmatrix} a_2 & b_2 & c_2 & \cdot & \cdot & \cdot & q_2 \\ a_3 & b_3 & c_3 & \cdot & \cdot & \cdot & q_3 \\ a_4 & b_4 & c_4 & \cdot & \cdot & \cdot & q_4 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ a_n & b_n & c_n & \cdot & \cdot & \cdot & q_n \\ \sum_{i=1}^{n} a_i & \sum_{i=1}^{n} b_i & \sum_{i=1}^{n} c_i & \cdot & \cdot & \cdot & \sum_{i=1}^{n} q_i \end{vmatrix}$$

and operate on A and B simultaneously. It can be shown by operation on rows that

$$A = (-1)^{n+1} B.$$

This property now affords a very simple check. Of course, to save computational labour the determinants A and B are not written out separately but jointly as a $(n+1) \times n$

*The elements of the last row in B could in fact be any linear combination of its rows, provided they contain the first row. This first row must however not be multiplied by a constant other than one.

matrix. The check row may now be multiplied by minus one if the order of the determinant is even, and left unaltered if it is odd, so that the final two entries are both identical in sign as well as magnitude.

ILLUSTRATIVE EXAMPLE

A numerical example should make the algorism quite clear. It is desired to evaluate the sixth-order determinant as given by

$$A = \begin{vmatrix} 2 & -2 & 0 & 0 & 1 & 2 \\ 4 & -3 & 3 & 1 & 6 & 1 \\ 0 & 2 & 4 & -6 & 2 & 2 \\ 5 & -7 & -2 & 1 & 1 & 1 \\ 1 & 2 & 3 & 2 & 3 & 2 \\ 2 & 1 & 2 & 4 & 2 & 2 \end{vmatrix}$$

It follows now that B may be written as

$$B = \begin{vmatrix} 4 & -3 & 3 & 1 & 6 & 1 \\ 0 & 2 & 4 & -6 & 2 & 2 \\ 5 & -7 & -2 & 1 & 1 & 1 \\ 1 & 2 & 3 & 2 & 3 & 2 \\ 2 & 1 & 2 & 4 & 2 & 2 \\ -14 & 7 & -10 & -2 & -15 & -10 \end{vmatrix}$$

Note that the last row in B is

$$\left[-\sum_{i=1}^{6} a_i, -\sum_{i=1}^{6} b_i, -\sum_{i=1}^{6} c_i, -\sum_{i=1}^{6} d_i, -\sum_{i=1}^{6} e_i, -\sum_{i=1}^{6} f_i \right],$$

as suggested in section 2.

A and B will be combined as shown:

$$\begin{bmatrix} 2 & -2 & 0 & 0 & 1 & 2 \\ 4 & -3 & 3 & 1 & 6 & 1 \\ 0 & 2 & 4 & -6 & 2 & 2 \\ 5 & -7 & -2 & 1 & 1 & 1 \\ 1 & 2 & 3 & 2 & 3 & 2 \\ 2 & 1 & 2 & 4 & 2 & 2 \\ \hline -14 & 7 & -10 & -2 & -15 & -10 \end{bmatrix} \rightarrow \begin{Vmatrix} 2 & -6 & 0 & -1 & -11 \\ -3 & 3 & 1 & 6 & \\ 8 & -18 & -22 & 38 & 10 \\ 2 & 4 & -6 & 2 & \\ -10 & 24 & -8 & -8 & 0 \\ -7 & -2 & 1 & 1 & \\ 17 & -17 & -7 & 1 & -1 \\ 2 & 3 & 2 & 3 & \\ -3 & 1 & 8 & -8 & 2 \\ 1 & 2 & 4 & 2 & \\ 28 & -24 & 36 & -56 & 10 \end{Vmatrix}$$

$$\rightarrow \begin{Vmatrix} -4 & 44 & -22 & 68 \\ -18 & -22 & 38 & \\ 6 & 168 & -80 & 40 \\ 24 & -8 & -8 & \\ 34 & 152 & -64 & 8 \\ -17 & -7 & 1 & \\ -17 & -43 & 24 & -2 \\ 1 & 8 & -8 & \\ 44 & 114 & -40 & 16 \end{Vmatrix} \rightarrow \begin{Vmatrix} 52 & -8 & 120 \\ 168 & -80 & \\ -200 & -176 & -240 \\ 152 & -64 & \\ -66 & -128 & -64 \\ -43 & 24 & \\ -46 & -127 & -38 \end{Vmatrix}$$

$$\rightarrow \begin{Vmatrix} -64 & -288 \\ -176 & \\ 92 & 304 \\ -128 & \\ -58 & -136 \end{Vmatrix} \rightarrow \begin{Vmatrix} -400 \\ -400 \end{Vmatrix}$$

Hence the value of $A = -400$.

CONCLUSIONS

The extra amount of work involved by introducing a check row (or check column, if found more convenient) is well compensated by the fact that a check has been kept for the accuracy of the work. The method will be found most useful to the programmer of high speed digital computors as well as to those with ordinary desk machines.

ACKNOWLEDGMENT

The author wishes to thank the Chief Scientist, Department of Supply, for permitting this note to be published.

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Graduates' and Students' Section

THOSE of you who have followed the various viewpoints which have been expressed in this page, on the subject of the Graduate's and Student's role in industry, may well have felt quite strongly about certain of the arguments expounded therein. However, we members of your Section Committee have not noticed any startling response in the way of written replies from among you.

Now it is certain that a spirit of frustration is widespread among many of the younger members of the Aircraft Industry, but the apathy apparent in your response to this page may well be a symptom of the reason for that feeling, *i.e.* too much talking but no positive action.

To some this may read as an attempt to arouse an insurrection among the junior technicians, though in fact all we are seeking is a more active response from what is, after all, a professional body whose position in society, at present, merits nothing like the respect and awe with which many of the public treat members of the other professions.

If you feel that there is little point in your writing to us on the particular problem of your place either in industry, or perhaps even more important, in the whole concept of our present day society, then maybe you could produce for us a few lines on some other subject, be it of a technical nature or otherwise, which might be of interest if published herein. Such an influx of editorial material would possibly justify our seeking an expansion from our present one page status to a broader platform. In fact, now that the busier season of activities is starting, a combination of some material from you, coupled with précis of the section lectures, and brief visit reports, should make this page one of those to which you first turn on receiving the JOURNAL.

We can offer no financial rewards for your efforts, but at least we can present you with a chance to give your news and views a wider circulation, and with the opportunity to say what you like, within reason, under a cloak of anonymity if you so desire. This is at least for some of you a chance not to be missed.

We await your replies.—P.D.S.

BOSCOMBE DOWN VISIT

SHORTLY after last month's notice went to press, saying that the Section's visit to Boscombe Down arranged for 29th August had had to be cancelled, another date was offered to us, namely 12th September. It was decided to accept this offer, for the cancellation had inconvenienced our hosts somewhat, and because many people had applied to come in the first place. It was apparent that by arranging lifts with members who had cars a trip was feasible.

So at last, on Wednesday 12th September, 26 members arrived at the Aeroplane and Armament Experimental Establishment for what turned out to be a most worthwhile visit on one of the few summer days of this year's monsoon season. Our hosts had gone to much trouble to show us as much as security permitted, and to clarify our impressions of what went on at Boscombe Down.

Short talks of welcome and introduction from the Chief Superintendent and his assistant emphasised that the function of A. and A.E.E. is testing, and the only type of research done in the line of new equipment to facilitate more efficient testing and assessment. The Branch Honorary Secretary at Boscombe Down, Miss Harrison, arranged for two of her members to conduct the party in two groups on a well-planned tour of the establishment.

An hour was spent inspecting the flight sheds where an almost Farnborough-type line up was to be seen—Valiants, Vulcans, Javelins, Hunters, etc., etc. There are three squadrons which specialise in fighters, heavy aircraft and naval aircraft. The largest hangar was built with the Brabazon in mind, so that a Vulcan and a Beverley barely half-filled it. There is a weighbridge built into the floor with a capacity of 140 tons. The man in charge claimed that a 2 lb. change could be detected in 60 tons. On this weighbridge, c.g. positions and some inertia data can be verified.

In the instrument section, all kinds of instruments and recorders were seen, and some of the calibration and test rigs, *e.g.* an altimeter in a cold chamber. A novel specialised instrument on its calibration rig was an R.A.E. electronic torquemeter as used on helicopter rotor shafts for power-input measurement.

A very good lunch was provided in the canteen, and after this each group set out to see what the other saw before lunch. A fourth squadron is concerned with airborne forces, and a current preoccupation is helicopters for army use. An inspection of a partially stripped helicopter was new ground for some people.

The famous blower tunnel, the only one in Western Europe, permits study on the ground of canopy, and auxiliary fuel tank jettisons and seat ejections with an airblast to order of about 300 knots magnitude.

In the armaments section we received a short talk on bombing and trials procedure, followed by a spectacular colour film on the efficacy of the Aden gun. This was demonstrated by shoot-ups of obsolete Spitfires on the ground by fighter aircraft with various types of guns.

The armament and gunnery people had their own instruments section which had developed specialised devices for film reading and automatic results analysis from camera gun records. Another device, with applications beyond those of the original design, counted and recorded every round fired from each gun against a time-base, so that tracing of gun-jamming and other faults was assisted, besides providing a record complementary to the camera films.

The visit closed with a film in the process of being edited which was to illustrate the activities of A. and A.E.E. It acted as a summary of what we had seen.

It was good to find that several members who were able to attend this visit were not based in the immediate vicinity of London.—N.K.B.

PARTIES AND DANCE

The Section's summer party was a great success; it even resulted in a small profit, despite the fact that a subsidy for it was planned. In view of members' enthusiasm about the party a similar one is proposed for next spring.

Meanwhile, plans are being made for the Section's annual dance, to be held at 4 Hamilton Place on Friday 30th November. Full details will be given in the next issue of the JOURNAL; it is hoped that members unable to be at the party will come to the dance.

THE LIBRARY

Reviews

COLLOQUIUM ON FATIGUE. *Stockholm, 1955. Proceedings. International Union of Theoretical and Applied Mechanics. Edited by Waloddi Weibull and Golke K. G. Odqvist. Springer-Verlag, Berlin, 1956. 339 pp. Illustrated. DM.46.50.*

No one now can expect to follow fatigue
Who does not command four languages,
English, French, German and Statistics.
(At Stockholm the hosts and their Danish
Dutch, Finnish, Italian and Russian guests
Gladly forwent their own mellifluous tongues
To gain the confidence of their Western neighbours).
This book is full of confidences
Of that queer kind that leave us
No more than ninety-five per cent assured
And no less than five per cent uncertain.
Statistics is the Science of Comparison,
It could have been of use to Polonius
To test the truth of Hamlet's observations
On the shape of clouds.
It can be no less use to us
To test the truth of the several theories
Of the real nature of fatigue,
And it can be no more.
Lacking all hypothesis, twenty, thirty, forty nor
A hundred test results get us no place;
With a good working hypothesis half-a-dozen
Might do very well.
Of the thirty-five papers read at Stockholm
Nearly one third
Deal chiefly with the shape of clouds
Of test results. As successive Hamlets
Stalk across the stage the reader may play
Polonius to them all. Or he may select
His own pet Hamlet and play Horatio to him
(The suggestion is kindly made: Horatio survived).
" At the end of the meeting some participants
Expressed the view
That the picture of research as conveyed
By the colloquium as a whole
Was a rather confusing one. It is believed
That the reading of the complete papers
Does not contradict this view."
(The lazy reviewer can always quote at length)
" Anyhow it would have exceeded the powers
Of the Organising Committee "
(To have invited someone to undertake)
" To summarise the papers so as to let
Different opinions and points of view
Stand out clearly "
But the points of view do stand out
Like crags: each surmountable by approved route
And scarcely two espiable one from the other.
To the top of our bents we may fool ourselves
With fancied resemblances to weasels
Or to more skew symmetric camels.
But among the drifting clouds
Of results from all over the Western hemisphere
(And a little East)
We shall not find our way from crag to crag
Until someone provides a reliable compass.
We may grope our way up the goat paths of Prot
and Probit
Under the lowering skies of cumulative damage
And still pray the gods for a safe return
To flat land.
Nonetheless this guide should be studied,
For study of the papers as a group
Encourages the hope that apparent confusion
May at last yield place to some semblance of order.
If this volume is read as widely as it deserves
Perhaps someone, somewhere may volunteer
To undertake the task that the Organising Committee
Found to be beyond its powers.—H. L. COX.

VAPOUR TRAILS. *Edited with a foreword by Mike Lithgow. Wingate, 1956. 199 pp. Illustrated. 13s. 6d.*

Long ago when I took a selection of pilots' complaints to a certain Permanent Secretary of the Air Ministry, he made it clear at once that he was not going to be particularly sympathetic by saying: " You know, pilots are a kittle-cattle lot." Only the other day an airline official let himself go on the alleged inability of the pilots to recognise any virtue or importance in the work done by anybody outside their own close corporation. And about the same time a former test pilot of the Gloster Company was saying without much restraint what he thought about British designers, " boffins " and engineers. Here, by way of a change, are ten test pilots telling their tales without any rancour and occasionally " carrying back the can " with all the humility of the débutante who tripped over her train.

Perhaps that was what my distinguished Welsh civil servant friend meant when he talked about " kittle-cattle "—that like spirited horses they tend to be temperamental and that the tension of taking the ultimate risks with contraptions, designed, built and maintained by other people, may lead them to be unduly critical or to demand too high a standard of perfection, no matter how accomplished they may be in their profession. In this book there is some evidence of the desperation that belongs sometimes to swift danger and narrow escapes but there is, too, plenty of evidence of sweet reasonableness and intelligent understanding of the reasons why two and two do not always make four in experimental aircraft. Listen, for example, to Ben Gunn on the subject of an elevon torn off the Boulton Paul 120 by flutter: " Every effort is made before an aircraft takes the air to prevent this sort of situation arising." That brand of flutter was almost impossible to simulate on the ground.

Or go with George Errington, who calls himself not test pilot but flying engineer, through almost a lifetime of devoted attention to all that concerns flying, or join Jimmy Orrell on his delicate mission in Canada; or go back to the early days with Henri Biard; or accompany Jeffrey Quill on his embarrassing crash landing on the *Argus*, and you will conclude that the test pilot is not all spleen, skill and high-strung egoism. I used to hold that the valuable test pilot was the type who could go from the cockpit to the drawing-board and make his points graphically and constructively. Now that cameras and instruments tell so much of the tale of what happens in the air, there is everything to be said for encouraging the test pilot to shoot his line and get the fatigue stresses out of his system.

—E. COLSTON SHEPHERD.

SPACE SHIPS AND SPACE TRAVEL. *Frank Ross, Jr. Museum Press, London, 1956. 166 pp. Illustrated. 12s. 6d.*
AN INTRODUCTION TO ROCKETS AND SPACE-FLIGHT. *Eric Burgess. Hodder and Stoughton, London, 1956. 96 pp. Illustrated. 12s. 6d.*

Public interest in space travel generates a continuing stream of " popular " books on the subject, although most of them add little or nothing to what has already been well said by Clarke, Ley, Gatland and the other select few authors who are themselves involved in the astronautical movement. (In fact, the only exception which immediately comes to mind, as being written by an " outsider," is the amusingly dispassionate " Flight Into Space," by J. N. Leonard, of *Time* magazine.)

However, one read somewhere the other day that an incredible total of nearly 20,000 book titles were published in the U.K. last year, and more than half as many in the U.S., too. This at least suggests, in passing, that the aircraft industry is not the only one in Britain which dissipates its effort over too many projects. Presumably, every publisher feels that he must have a title in his list on almost any and every subject of contemporary concern, and finds a writer, not necessarily particularly well-informed or endowed with great originality, to produce a pot-boiler on it for him. Then again one reads of difficulties in the book trade; perhaps there is a lesson for us here?

Mr. Ross's book at least has the merit of being well-produced and well-illustrated. It is also very comprehensive, although quite short, for it covers the history of rocketry, the exploration of the upper atmosphere by rockets, planetary astronomy, and most current ideas on space flight and the various possible types of space ship. In fact, an intelligent teen-ager (or other lay reader) would admittedly gain quite a fair impression of the subject from reading just this single book, and moreover without being exposed to too much inaccuracy.

However, the claim on the dust-jacket that the book is " scientifically accurate " is something of an over-statement. Without discovering any really glaring errors or absurdities, one nevertheless encounters a number of instances which suggest that the author has not *quite* properly understood all the source material which he has obviously read. For example, one reads that: " At one time it was thought that weightlessness was caused by the gravitational forces of the earth and the moon balancing one another out at some point in the space realm." (Who by?) " Now astronauts know that it is really the centrifugal force of the speeding object in space and the earth's gravity force that originate this peculiar sensation." (Well . . . !) And again, on a return journey from the moon: " Once the rocket ship has re-entered the gravitational field of the earth, the rocket motors will be shut off." (Of course, they could be shut off just as soon as the ship had acquired sufficient velocity to coast to the null point in the earth-moon field.)

No similarly misleading statements are to be found in Mr. Burgess's book, unless one includes a decidedly optimistic view that ground-to-air guided weapons have already made the strategic bomber obsolete. As far as space-flight is concerned, Mr. Burgess in fact speaks from the inside of the movement, having been one of the founders of the post-war British Interplanetary Society. His book is shorter than the previous one reviewed, is perhaps rather less comprehensive, and many of its illustrations (drawn by the author himself) are somewhat amateurish compared with other excellent examples in many similar books for a comparable audience. In short, one could fairly say of these two books that interested readers could do worse than read either, but they could do better, although usually only for the expenditure of a little more money.—A. V. CLEAVER.

FUNDAMENTALS OF VIBRATION ANALYSIS. *By N. O. Myklestad. McGraw-Hill, New York, 1956. 260 pp. Diagrams. 49s.*

As its title implies, this is an elementary book. Briefly, it covers free and forced linear vibration (both damped and undamped) of systems having one degree of freedom and systems having several degrees of freedom. There are also chapters on non-viscous damping of systems having one degree of freedom, the use of generalised co-ordinates and, finally, tabular methods for finding natural frequencies.

The theory is introduced simply and is lavishly illustrated by examples. Many of these are worked out and all have answers given. In the reviewer's opinion this is an excellent feature of the book. The treatment of vibration measurement is also excellent.

The author omits all discussion of systems having infinite freedom except in so far as continuous bodies can often be treated approximately as if they possess finite freedom (as in Holzer's method). This omission is presumably made because the motion of these bodies is governed by partial differential equations, and these raise certain difficulties. It is quite true—they do; but, then, so do Lagrange's equations and they find a place in the book. Both of these topics have their difficulties and surely the vibration of continuous bodies is the more immediately important to engineers.

Dr. Myklestad's treatment of the Lagrangean method is interesting. He contrives to give a really simple approach to the subject which, in the reviewer's opinion, should be regarded as the first round—to be followed by the full treatment. In particular, normal co-ordinates are introduced and it is shown that each is a measure of distortion in a normal mode. They are not derived (as is so often the case) as a set of co-ordinates which make the kinetic and potential energies the sums of terms containing only the squares of generalised velocities and displacements respectively. This method has much to commend it, although readers of the book may be misled by the author's comment that " the normal coordinates are . . . . identical with the normal modes . . . ."

The treatment of damped free vibration of systems having several degrees of freedom demands special mention. For, according to the publisher's " blurb ", the author " introduces the concept of damped modes of free vibration ". This presumably means that much of the theory of Section 25 is original; it is certainly new to the reviewer. The author starts by explaining in very simple terms the classical theory of damped free motion (*e.g., see* Lamb's *Higher Mechanics*, 1920, Art. 97). Referring specifically to the problem of light damping, the author then explains the concept of a " damped mode ", with inadequate justification. The question of how accurate this approximate treatment is must surely be regarded as being still open. It is certainly inadequate when there are close natural frequencies and appears to be less useful than the method of Rayleigh (*Theory of Sound*, 1894, Art. 102).

This reviewer does not believe (as some do) that an elementary book must necessarily contain hordes of references to the literature in order to acquire respectability. Researchers whose work is incorporated in elementary texts should not feel aggrieved when their

results are used without acknowledgment; it is a compliment. This is an elementary book and it contains almost no references whatever. Now although this is not a serious shortcoming, it would help if a few were given, if only because a lucid introduction to a subject may leave the reader eager to dig deeper. Thus a reference to Jacobsen's paper on "equivalent viscous damping" (Trans. A.S.M.E., 1930) would be helpful in the chapter on non-viscous damping. Again, the author is far too modest in this respect about his own considerable contributions to vibration theory.—R. E. D. BISHOP.

HIGH TEMPERATURE TECHNOLOGY. *Edited by I. E. Campbell. John Wiley and Sons, New York, 1956. 526 pp. Illustrated. 120s.*

This excellent book, written by a team of experts, is the sequel to a symposium, and its main appeal will probably be to other experts. For them, widely scattered information is conveniently available in one volume. It should not be thought, however, that the book is just another of those written in highly specialised language for experts only. On the contrary, after an introduction which paints a general picture of the evolution of modern non-argillaceous refractories under the pressure of industry, science, and not least, the needs of national defence, there follows a treatise, for the non-specialist and the specialist alike, which deals with the technological problems associated with very high temperatures. These may be defined roughly as temperatures exceeding 1500°C.

The main sections of the book are concerned with materials, with methods, and with measurements. The materials include metals, oxides, carbon and graphite, carbides, borides, silicides, sulphides, and cermets. The detailed list is not too different from that which appeared in 1897 in Henri Moissan's famous book, "Le Four Electrique." In Moissan's time, however, many of the materials were far from pure, and fabrication into articles of useful shape and density was rarely straightforward. The standards of purity are now much higher, and satisfactory fabrication is possible in many cases.

The section dealing with methods contains an interesting discussion of the theories of agglomeration of granular compacts under the influence of high temperatures accompanied in some cases by fairly high external pressures. The rest of the section is devoted to the means of producing high temperatures. The methods described include the use of the electronic torch, and the concentration of solar radiation by means of mirrors. Furnaces depending on combustion are not discussed, but references to literature are given.

The last section describes the means of measuring at high temperatures various physical properties, including mechanical properties and temperature itself. There are also articles on microscopy and X-ray diffraction in connection with materials at very high temperatures.

The printing and diagrams are of good quality, but the half-tone illustrations are mediocre. Fortunately, the effects of this mediocrity are unimportant.—VAUGHAN H. STOTT.

50 JAHRE GRENZSCHICHTFORSCHUNG. *Edited by H. Görtler and W. Tollmien. Friedr. Vieweg & Sohn, Braunschweig, 1955. 499 pp. Illustrated. German, French and English. £5 17s. 6d.*

The modern science of aerodynamics may well be held to date from the publication in 1904 of Ludwig Prandtl's fundamental and epoch-making paper which introduced the concept of the boundary layer for the first time. Since then, boundary layer theory has proved an indispensable tool for the understanding of aerodynamic phenomena, and it has enabled a vast range of apparently intractable fluid flow problems to be satisfactorily resolved. The mathematical theory of the boundary layer has been energetically developed in many diverse directions, Prandtl and those who came under his inspiration at Göttingen always being in the forefront of the advance. This commemoration book was planned as a tribute to Prandtl, to be presented to him on the occasion of the fiftieth anniversary of the publication of his original paper. Prandtl died in 1953, in his 79th year, and the book is now offered as a monument to his memory.

The book consists of a collection of nearly fifty contributions by research workers from all over the world. Over half are written in English, the remainder being in German, apart from one which is in French. The majority are concerned with mathematical boundary layer theory, although there are also a number of experimental papers. They deal with current research problems, and taken together they afford an impressive demonstration of the great range of topics and techniques to be found in modern boundary layer theory.

The value of the book to the student is questionable. Many of the articles can hardly be read without frequent reference to previously published papers, and often the relation of the work to the body of established knowledge is not made clear. Few of the papers have any really significant advance in boundary layer theory to report; the majority concern developments or extensions of previous work. It might perhaps have been more valuable to have had a rather smaller number of contributions, each describing the range of application of boundary layer theory in a particular field, noting problems which have been solved and others which are still under attack. However, the book includes a large number of references to current research work, as well as impressing by its range of application, and a study of the various mathematical techniques employed may well serve to open the eyes to unsuspected possibilities of boundary layer theory.—M. B. GLAUERT.

AERONAUTICAL - ENGLISH; TECHNICAL POCKET - DICTIONARY AND MANUAL OF AVIATION, VOL. I. *Alfred Opperman. Aeronautische Verlags- und Luftreklamegesellschaft, Munich, 1955. 1,170 pp. Illustrated. 19 DM.*

This book is a fair example of the thoroughness with which we associate the German mind. It is, presumably, produced to help those connected with the re-birth of civil aeronautics in Germany and—it is good.

To start with we have a 600-page German-English English-German aeronautical dictionary. This is followed by conversion tables (which not only put litres into Imperial gallons but also into U.S. units), then a list, or rather a 145-page section on abbreviations. Next comes a section called "Funksprechverkehr"—translated "Voice"—which appears to cover every phrase (official phrase that is) that air crews are likely to hear over the radio-telephone. Navigation and Meteorology sections follow this and then come "Illustrated Definitions of Aircraft-Components, Engines and Tables." This, with the following three sections, on Aircraft, Engines and performance tables form a not-so-miniature Jane's and the book is rounded off with a classified list of aeronautical books (priced in dollars).

One small criticism. It would be impossible to index this book, but the table of contents should indicate the page number of each section.

THE MOUCHOTTE DIARIES, 1940-1943. *Edited by André Dezarrois. Staples Press, London, 1956. 220 pp. 15s.*

René Mouchotte escaped from French territory on 30th June 1940, just ten days after the fall of France. With five comrades, he flew in a stolen aeroplane from Oran to Gibraltar and became one of the first of the Free French under de Gaulle.

Mouchotte's diary begins with this escape and ends in July 1943, shortly before his death in action. He spent these three eventful years in Great Britain, flying Hurricanes and Spitfires, first with R.A.F. squadrons in the defence of London and later with the Free French Squadrons. In the summer of 1943, Mouchotte was commander of the French "Alsace" Squadron at Biggin Hill and was leading the entire wing when, on 27th August 1943, he was killed in action.

"These pages are intended to be read only by me in some years' time," he writes. His story is therefore of the war as it affected Mouchotte. Flying often makes him vomit; he blacks out easily; he frequently complains of exhaustion—but complains more bitterly whenever he is posted away from active fighting! A sickening series of crashes and losses in combat, which deprive him of most of his early colleagues, depresses him to an extent seldom admitted in autobiography.

What sustained him? His love for France, personified by his mother (who spent the war in France, knowing that René was with de Gaulle but knowing nothing of his flying), and his contempt for all Frenchmen who did not fight Germans. The diary is supplemented by appendices describing the last operation he led and containing a tribute to his leader by Pierre Closterman, Mouchotte's "Number Two" on his last flight.—A. H. YATES.

THE COMPLETE GUIDE TO LONDON AIRPORT. *Sir Miles Thomas. 33 pp. Illustrated. Pitkin Pictorials, London. 1956. 2s. 6d.*

This lavishly illustrated booklet would form a delightful souvenir of a visit to, or landing at or departure from, London Airport. It is obvious that Sir Miles would not put his name to any publication that was not completely authoritative and this should be sufficient recommendation. For such a comparatively small guide the number of acknowledgments is quite amazing and this indicates the amount of information and number of photographs packed into the 33 pages. There is a short historical survey and the various departments concerned with the departure and arrival of aircraft are sketched in. A convenient "Spotters' Guide" lists "users" in alphabetical order of registration letters, make of aircraft and, where applicable, their names.—F.H.S.

A PENGUIN IN THE EYRIE. *Hector Bolitho. Hutchinson, London, 1955. 254 pp. Illustrated. 18s.*

Sub-titled "An R.A.F. Diary 1939-1945", this book is based on the diaries written by Hector Bolitho while serving as an Intelligence Officer, first with the Air Ministry, and then with Coastal Command, finally among the anti-U-boat squadrons during the invasion of Normandy. Among the diary entries are many fascinating stories of unbelievable courage, but as a whole the book lacks cohesion. The author's earlier books, *War in the Strand* and *Task for Coastal Command* included a considerable part of what is published in the present volume, and this may be the reason why the over-riding impression is of "scissors-and-paste".

FIGHTER PILOT. *Wing Cdr. Paul Richey. Hutchinson, London. Revised Edition, 1955. 192 pp. 10s. 6d.*

When this book was originally published (by Batsford) in 1941 the JOURNAL contained a review which said "it has the transparent sincerity of a diary or a home letter". When it was reproduced in an omnibus volume "Youth at War" in 1944, the JOURNAL referred to the previous review and added "it remains one of the most vivid and personal narratives that have yet been written". This latter still holds good despite the avalanche of reminiscence that the war precipitated. The Library held two copies of the original and one of the omnibus version. All three have disappeared so it would seem that some people think highly enough of the book to want a copy for themselves.—F.H.S.

AUTOMATION, FRIEND OR FOE? *R. H. MacMillan. Cambridge University Press, 1956. 100 pp. Illustrated. 8s. 6d.*

This little treatise has much to commend it. The fact that the author is in the Department of Engineering at Cambridge should guarantee reasoned arguments but they are in language that everyone can understand. It is reasonably priced and is a handy pocket size.

It is not a book for the man who wishes to convert a system to automation but rather for one who wishes to discuss intelligently the pros and cons of something that may change our way of life in less than a decade—F.H.S.

Additions to the Library

**Aeroplane.* THE AEROPLANE DIRECTORY. 1956.
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* *Items marked thus are for reference use only.*

Reports

AERODYNAMICS

Boundary Layer

See Testing and Instruments

Compressible Flow

See also Mathematics

Calculated spanwise lift distributions, influence functions, and influence coefficients for unswept wings in subsonic flow. F. W. Diederich and M. Zlotnick. N.A.C.A. Report 1228. (1955).

Spanwise lift distributions have been calculated for nineteen unswept wings with various aspect ratios and taper ratios and with a variety of angle-of-attack or twist distributions, including flap and aileron deflections, by means of the Weissinger method with eight control points on the semi-span. Also calculated were aerodynamic influence coefficients which pertain to a certain definite set of stations along the span, and several methods are presented for calculating aerodynamic influence functions and coefficients for stations other than those stipulated.—(1.2.1.1 × 1.6.1).

Shock-turbulence interaction and the generation of noise. H. S. Ribner. N.A.C.A. Report 1233. (1955).

Interaction of convected field of turbulence with shock wave is analysed to yield modified turbulence, entropy spottiness, and noise generated downstream of the shock.—(1.2.3.2).

Investigation at supersonic speeds of the variation with Reynolds number and Mach number of the total, base, and skin-friction drag of seven boattail bodies of revolution designed for minimum wave drag. A. F. Bromm, and J. M. Goodwin. N.A.C.A. T.N. 3708. (*June* 1956).

Results are presented from an investigation of the variation with Reynolds number and Mach number of the total, base, and skin friction drag of seven boat-tail bodies of revolution designed for minimum wave drag according to the theory of N.A.C.A. T.N. 2550. The tests covered a Reynolds number range from approximately $1{\cdot}0 \times 10^6$ to $10{\cdot}0 \times 10^6$ at Mach numbers of 1·62, 1·93, and 2·41, respectively.—(1.2.3).

Theoretical wave drag of shrouded airfoils and bodies. P. F. Byrd. N.A.C.A. T.N. 3718. (*June* 1956).

Formulae for the wave drag of shrouded symmetrical aerofoils and shrouded bodies of revolution of arbitrary shape are derived by means of linearised theory. In the case of the aerofoils, the shroud consists of flat plates and for the bodies of revolution the shroud is a cylindrical shell. The results obtained hold for a Mach number range dependent on the geometry of the configuration. Expressions are also given for determining a class of body shapes for which the wave drag is theoretically zero.—(1.2.3.2).

Fluid Dynamics

The free streamline method applied to the flow at the rear of a duct. A. H. Craven. C. of A. Report No. 99.

The free streamline technique is extended to the problem of two-dimensional jet flow from the rear of a nacelle. Complex potentials for the jet flow in the free stream are found and from these the equation of the wake streamline and the velocity and pressure distributions are calculated. Some consideration is also given to the corresponding axi-symmetric problem.—(1.4).

A potential flow model for the flow about a nacelle with jet. A. H. Craven. C. of A. Report No. 101.

The inviscid incompressible flow round a thin nacelle from which a jet is issuing is considered. It is shown that the inhomogeneous motion can be transformed into an equivalent homogeneous motion which may be represented by two semi-infinite distributions of vortices in the two-dimensional case and by a semi-infinite distribution of circular vortex rings in the axi-symmetric case.—(1.4.1).

Sur la turbulence spatialement homogène d'un fluide compressible. M. Krzywoblocki. Pub. Sc. et Tech. No. 314. (1956).

Extension aux fluides compressibles de l'utilisation des fonctions aléatoires dans la théorie statistique de la turbulence.—(1.4.2).

Internal Flow

Beitrag zur Berechnung von Sekundarstromungen. E. Becker. Max-Planck Institut. Mitteilung. Nr. 13. (1956).—(1.5.1.1).

Analysis of gas flow systems for dynamic control purposes. W. K. McGregor, et al. AEDC. ASTIA Doc. No. AD 88130. (*April* 1956).

Results are presented of an investigation of the problems involved in the design of an automatic pressure control system. Methods are developed for the prediction of frequency and indicial response of gas flow systems on both a lumped parameter and a distributed parameter.—(1.5.1).

Stall propagation in axial-flow compressors. A. H. Stenning et al. N.A.C.A. T.N. 3580. (*June* 1956).

A theory for the prediction of the stall propagation velocity in axial-flow compressors has been developed and compared with experiments on a stationary circular cascade and a single stage compressor.—(1.5.2.1).

A study of the high-speed performance characteristics of 90° *bends in circular ducts. J. T. Higginbotham, et al. N.A.C.A. T.N.* 3696. (*June* 1956).

Four 90° bends in ducts of constant diameter with ratios of radius of curvature to diameter (r/d) of 0·75, 1·00, 2·50, and 4·00 have been investigated with both a thin and a thick inlet boundary layer to determine the choke Mach number and general performance of each of the elbows.—(1.5.1.2).

Loads

See also Compressible Flow and Wings and Aerofoils

Measurement of aerodynamic forces for various mean angles of attack on an airfoil oscillating in pitch and on two finite-span wings oscillating in bending with emphasis on damping in the stall. A. G. Rainey. N.A.C.A. T.N. 3643. (*May* 1956).

The oscillating air forces on a two-dimensional wing oscillating in pitch about the mid-chord have been measured at various angles of attack and at Mach numbers of 0·35 and 0·7.—(1.6.3 × 1.10.2.2).

Stability and Control

Measurements of pitching moment derivatives for a series of rectangular wings at low wind speeds. P. R. Guyett and D. E. G. Poulter. C.P. 249. (1956).

The direct aerodynamic moments for pitching oscillations have been measured on a series of rectangular wings having aspect ratios between 2 and 8 for axis positions at the wing leading edges and trailing edges. Two of the wings were also tested with single end plates which were aerodynamically effective in doubling the wing geometric aspect ratio. The measurements covered the range of frequency parameter (based on wing chord) 0·13 to 0·39.—(1.8.2.2).

Static longitudinal and lateral stability characteristics at low speed of unswept-midwing models having wings with an aspect ratio of 2, 4, *or* 6. *W. D. Wolnart and D. F. Thomas. T.N.* 3649. (*May* 1956).

An experimental investigation was made at low speed in the Langley stability tunnel to determine the static longitudinal and lateral stability characteristics of unswept-mid-wing models having wings with an aspect ratio of 2, 4 or 6 through an angle of attack range from −4° to 32°.—(1.8.1.2 × 1.8.2.2).

Investigation at zero forward speed of a leading-edge slat as a longitudinal control device for vertically rising airplanes that utilize the redirected-slipstream principle. R. E. Kuhn. N.A.C.A. T.N. 3692. (*May* 1956).

Results are presented of an investigation of a leading-edge

NOTE.—*The figures in parenthesis at the end of each Summary are for office use only.*

slat as a longitudinal control device for vertically rising aeroplanes, in hovering flight. The model consisted of a semi-span wing equipped with a 60 per cent chord and a 30 per cent chord slotted flap operating in the slipstreams of two large diameter propellers.—(1.8.2.2).

Preliminary investigation of the effectiveness of a sliding flap in deflecting a propeller slipstream downward for vertical take-off. R. E. Kuhn and K. P. Spreemann. N.A.C.A. T.N. 3693. (*May* 1956).

Results are presented of an investigation of the effectiveness of a sliding flap in deflecting propeller slipstreams downward for vertical take-off. The model consisted of a semi-span wing equipped with a 50 per cent chord sliding flap and a 25 per cent chord plain flap.—(1.8.2.2).

Preliminary wind-tunnel tests of triangular and rectangular wings in steady roll at Mach numbers of 1·62 *and* 1·92. *C. E. Brown and H. S. Heinke. N.A.C.A. T.N.* 3740. (*June* 1956).

Damping-in-roll coefficients for a series of triangular plan form wings and two rectangular plan form wings have been obtained from supersonic-tunnel tests. The wings were mounted on a body of revolution and tests at Mach numbers of 1·62 and 1·92.—(1.8.1.2).

Investigation of lateral control near the stall: flight tests with high-wing and low-wing monoplanes of various configurations. F. E. Weick and H. N. Abramson. N.A.C.A. T.N. 3676. (*June* 1956).

Flight tests were made with typical light aeroplanes to investigate possibilities for obtaining reliable lateral control at low flight speeds. The maximum angle of attack below the stall at which control is still available was determined for each aeroplane, as well as the elevator deflection required to trim at this condition, with power off and on, and to make a three-point landing. One aeroplane was tested with different horizontal tail configurations in an attempt to provide an arrangement that would give near-optimum conditions with regard to the effect of power change on longitudinal trim near the stall.—(1.8.2.1 × 13.2).

Investigation of lateral control near the stall. Analysis for required longitudinal trim characteristics and discussion of design variables. F. E. Weick and H. N. Abramson. N.A.C.A. T.N. 3677. (*June* 1956).

Analytical design procedures for estimating the elevator deflection required to trim in steady longitudinal flight are presented. Pertinent data and formulae for use in evaluating longitudinal trim characteristics are summarised from existing literature and two light aeroplanes are analysed quantitatively to illustrate the use of the methods and to provide a comparison with flight-test results.—(1.8.2.1).

THERMO-AERODYNAMICS. *See* POWER PLANTS

WINGS AND AEROFOILS

See also LOADS

Methods for calculating pressure distributions on oscillating wings of delta type at supersonic and transonic speeds. F. Hjelte. KTH Aero T.N. 39. (1956).

The derivation and application are given of some approximative methods for calculating pressure distributions and aerodynamic forces on oscillating wings of delta type. The methods were derived for supersonic speeds, but are valid also for transonic speeds. Linearised theory has been used.—(1.10.1.2 × 1.6.3).

An investigation of the lift, drag, and pitching moment characteristics of AGARD calibration models A and B. C. J. Schueler and W. T. Strike. AEDC. AD-81581. (*Feb.* 1956).

An investigation of the lift, drag, and pitching moment characteristics of AGARD Calibration Models A and B has been made in Tunnel E-1 of the Gas Dynamics Facility, Arnold Engineering Development Center. The tests on Calibration Model A covered a Mach No. of 2·0 to 4·0 and a Reynolds number of $1{\cdot}5 \times 10^6$ to 27×10^6. Model B was tested over a Mach number range of 1·7 to 4·0 and a Reynolds number range of 3×10^6 to 22×10^6.—(1.10.2.2).

Investigations at supersonic speeds of 22 *triangular wings representing two airfoil sections for each of* 11 *apex angles. E. S. Love. N.A.C.A. Report* 1238. (1955).

The results of tests of 22 triangular wings, representing two leading edge shapes for each of 11 apex angles, at Mach numbers of 1·62, 1·92, and 2·40 are presented and compared with theory. All wings have a common thickness ratio of 8 per cent. and a common maximum-thickness point at 18 per cent. chord. Lift, drag, and pitching moment are given for all wings at each Mach number.—(1.10.2.2).

A correlation by means of transonic similarity rules of experimentally determined characteristics of a series of symmetrical and cambered wings of rectangular plan form. J. B. McDevitt. N.A.C.A. Report 1253. (1955).

The transonic similarity rules have been used to correlate the experimental lift, drag, and pitching-moment data, obtained by use of the transonic bump technique, for a series of 40 rectangular wings having N.A.C.A. 63A0XX, 63A2XX and 63A4XX sections, aspect ratios from ½ to 6, and thicknesses from 2 to 10 per cent.—(1.10.2.2).

Approximate indicial lift functions for several wings of finite span in incompressible flow as obtained from oscillatory lift coefficients. H. A. Drischler. N.A.C.A. T.N. 3639. (*May* 1956).

The unsteady lift functions for a wing undergoing a sudden change in sinking speed are presented for delta wings having aspect ratios of 0, 2, and 4 and for rectangular and elliptical wings with aspect ratios of 0, 3, and 6. For the elliptical and rectangular wings the local lift functions are also presented.—(1.10.1.2 × 1.6.3).

Wind-tunnel investigation of the effect of clipping the tips of triangular wings of different thickness, camber, and aspect ratio: transonic bump method. H. F. Emerson. N.A.C.A. T.N. 3671. (*June* 1956).

Transonic aerodynamic characteristics are presented for four basic triangular wings having aspect ratios of 2·0, 2·5, 3·0, and 4·0, and for these wings when their tips were progressively clipped to provide taper ratios of 0·1, 0·2, 0·3, 0·4 and in some cases 0·5.—(1.10.2.2).

Experimental measurements of forces and moments on a two-dimensional oscillating wing at subsonic speeds. S. A. Clevenson and E. Widmayer. N.A.C.A. T.N. 3686. (*June* 1956).

Experimental results of lifts and moments about the quarter chord of a two-dimensional wing at subsonic Mach numbers are presented. A comparison of the experimental magnitude of the lift vector with the theory as given by Dietze showed good agreement.—(1.10.2.1).

Flight tests at supersonic speeds to determine the effect of taper on the zero-lift drag of sweptback low-aspect-ratio wings. M. Pittel. N.A.C.A. T.N. 3697. (*June* 1956).

Comparison of experimental flight test results with theoretical calculations to determine the effect of wing taper and aspect ratio on the zero lift drag of wings with thin double-wedge sections at supersonic speeds is presented.—(1.10.2.2 × 1.12.2).

The flow past an unswept- and a swept-wing-body combination and their equivalent bodies of revolution at Mach numbers near 1·0. *W. F. Lindsey. N.A.C.A. T.N.* 3703. (*June* 1956).

The complete flow fields past an unswept and a swept wing-body combination and their equivalent bodies of revolution at Mach numbers around 1·0 have been observed by means of motion-picture Schlieren photography.—(1.10.2.2).

An investigation of foward-located fixed spoilers and deflectors as gust alleviators on an unswept-wing model. D. R. Croom, et al. N.A.C.A. T.N. 3705. (*June* 1956).

The results and discussion are presented of an investigation in the Langley 300 m.p.h. 7 by 10 ft. tunnel and the Langley gust tunnel to determine the longitudinal aerodynamic characteristics and the gust alleviation capabilities of forward-located fixed spoilers, deflectors, or spoiler-deflector combinations on a simulated transport aeroplane model having an unswept wing.—(1.10.2.2).

Comparison between experimental and predicted downwash at Mach number of 0·25 behind a wing-body combination having a triangular wing of aspect ratio 2·0. N. E. Sorensen and E. J. Hopkins. N.A.C.A. T.N. 3720. (*May* 1956).

A comparison is made between experimental and predicted downwash angles and span load distributions for a wing-body combination (maximum diameter to wing span ratio = 0·259) through an angle-of-attack range from 0° to 20°.—(1.10.2.2).

TESTING AND INSTRUMENTS

See also WINGS AND AEROFOILS

Analysis of strain gauge bridge networks for wind tunnel use. R. J. Sandeman. A.R.L. Note A. 149. (*January* 1956).

Some null-balancing networks for use with strain gauge bridges have been analysed. The requirements of sensitivity, linearity, zero load adjustment and stability have been considered on the basis of measuring the loads on wind tunnel models.—(1.12.6.2).

*On-line automatic data reduction tunnel E-1 gas dynamics facility. C. L. Hall and R. E. Klautsch. AEDC. ASTIA Doc. No. AD-*88490. (*April* 1956).

An automatic data reduction system is described which is capable of measuring, scanning, computing, and presenting the results of a wind tunnel test in one continuous operation. Operating modes of the components of the system are described as they apply to an actual test in Tunnel E-1 of the Gas Dynamics Facility.—(1.12.6).

*Investigation of a multiple-source Schlieren system for application to a perforated wall wind tunnel. M. Pindzola and G. R. Mozer. AEDC. ASTIA Doc. No. AD-*87754. (*April* 1956).

The results are presented of an investigation of a multiple-source Schlieren system for application to wind tunnels employing perforated walls. Visibility equations are derived showing the influence of geometrical parameters on the Schlieren photograph background pattern for first one and then two tunnel walls.—(1.12.6).

N.A.C.A. transonic wind-tunnel test sections. R. H. Wright and V. G. Ward. N.A.C.A. Report 1231. (1955).

An approximate subsonic theory has been developed for the solid blockage in a circular wind tunnel with walls slotted in the direction of flow. Pressure distributions over the surface of a non-lifting model in the slotted tunnel were compared with those obtained over the same model in a much larger tunnel where the interference was negligible.—(1.12.1.2).

Time correlator for problems in aerodynamics. G. T. Skinner. N.A.C.A. T.N. 3682. (*June* 1956).

An instrument of fairly simple design for measuring time correlation functions of two stationary random electrical signals is discussed. It is intended primarily for use in problems connected with aerodynamically produced acoustic fields but has suitable properties for application to a rather wide range of aerodynamic problems involving turbulent fields.—(1.12.6).

A sonic-flow orifice probe for the in-flight measurement of temperature profiles of a jet engine exhaust with afterburning. C. D. Havill and L. S. Rolls. N.A.C.A. T.N. 3714. (*May* 1956).

A temperature measuring system using two sonic-flow orifices in series is described. This system was adapted to measure the exhaust gas temperature of an afterburning jet engine and was mounted in a swinging Pitot-static probe. —(1.12.5 × 13.3).

An evaluation of four experimental methods for measuring mean properties of a supersonic turbulent boundary layer. G. J. Nothwang. N.A.C.A. T.N. 3721. (*June* 1956).

Surveys were made through the flat plate turbulent boundary layer at a Mach number of 3 using a Pitot probe, an X-ray densitometer, and cold-wire and hot-wire probes.—(1.12 × 1.1.3.4).

Application of scattering theory to the measurement of turbulent density fluctuations by an optical method. H. A. Stine and W. Winovich. N.A.C.A. T.N. 3719. (*June* 1956).

It is shown that photometric measurements in the scattered field produced by passing an unpolarised plane light wave through a non-absorbing turbulent fluid can be used to define an average integral scale and average intensity of density fluctuations. The analysis is based upon the scattering coefficient deduced by Booker and Gordon for a turbulence model having isotropic fluctuations and an exponentially decaying correlation function.—(1.12 × 32.2.4).

AEROELASTICITY

Quelques aspects des essais de vibration au sol et en vol. R. Mazet. O.N.E.R.A. Note Technique No. 34. (1956).—(2).

AIRCRAFT

Performance analysis of fixed- and free-turbine helicopter engines. R. P. Krebs and W. S. Miller. N.A.C.A. T.N. 3654. (*June* 1956).

Generalised performance charts are given for these engines and comparison is made of off-design specific fuel consumption, altitude performance, power-speed characteristics, and response times. Flight performance results for an assumed 30,000-pound helicopter powered by the fixed and free turbine engines are given.—(3.9).

FLIGHT TESTING

See also AERODYNAMICS—STABILITY AND CONTROL

Equipment used for boundary layer measurements in flight. F. M. Burrows. CoA Note 49. (*July* 1956).

Some notes are presented relating to the design and construction of a large multitube manometer and to two "fixed head" type boundary layer combs to be used for the measurement in flight of the boundary layer characteristics of a swept-back wing.—(13 × 1.12.5).

Error in airspeed measurement due to the static-pressure field ahead of an airplane at transonic speeds. T. C. O'Bryan, et al. N.A.C.A. Report 1239. (1955).

Measurements of static-pressure error ahead of sharp-nose bodies, open-nose air inlets, and ahead of the wing tip of a swept-wing fighter aeroplane model have been made at transonic speeds by use of the N.A.C.A. wing-flow method. —(13.3 × 1.12.2).

HYDRODYNAMICS

Investigation of high length/beam ratio seaplane hulls with high beam loadings. Hydrodynamic stability, Part 13. *The effect of afterbody angle on stability and spray characteristics. D. M. Ridland. C.P.* 236. (1956).

The effects of afterbody angle on longitudinal stability, spray and directional stability characteristics and elevator effectiveness are deduced from the results of tests on three models of the series which were alike in every major respect except that of afterbody angle. The models had afterbody angles of 4°, 6° and 8° respectively.—(17.1).

Investigation of high length/beam ratio seaplane hulls with high beam loadings. Hydrodynamic stability, Part 21. *Some notes on the effect of waves on longitudinal stability characteristics. D. M. Ridland. C.P.* 237. (1956).

The results are given of tests on three models of the series, designed to provide information on the correlation between stability with disturbance and stability in waves.—(17.1).

A theoretical and experimental investigation of the lift and drag characteristics of hydrofoils at subcritical and supercritical speeds. K. L. Wadlin, et al. N.A.C.A. Report 1232. (1955).

A theoretical and experimental investigation was made of the effect of the free-water surface and rigid boundaries on the lift and drag of an aspect-ratio-10 hydrofoil at both subcritical and supercritical speeds and of an aspect-ratio-4 hydrofoil at supercritical speeds.—(17.2).

Preliminary investigation of self-excited vibrations of single planing surfaces. E. J. Mottard. N.A.C.A. T.N. 3698. (*June* 1956).

The effect of various planing-surface shapes, conditions of

restraint, loads, trims, and speeds on the occurrence of self-excited vibrations was sought. Data are presented for the range of variables likely to be encountered with aeroplane hydro-skis.—(17.2 × 33.1.2).

MATERIALS

The effect of vibrations on the mechanical properties of H. R. Crown Max and Nimonic C.75. J. Jagaciak and J. W. Jones. CoA Report 91. (*Sept.* 1955).

Test castings were designed to produce data which would help in the production of gas turbine blades as castings. For castings in H.R. Crown Max the investigation is limited to the effect of subsonic frequencies and range of amplitudes; but in experiments on Nimonic C.75, both subsonic and sonic ranges of frequency were investigated.—(21.1).

Unnotched and notched rotating cantilever fatigue tests on Bristol "Freighter" spar boom material DTD 364. *J. Y. Mann. A.R.L. Note SM.*224. (*December* 1955).

Rotating cantilever fatigue tests were made on unnotched and notched specimens taken from the Centre Section Front Spar Lower Boom of a Bristol "Freighter" aircraft. For comparison, a small number of notched fatigue specimens, taken from the Port Front Spar Lower Boom of a crashed Bristol "Freighter" aircraft were also tested. There was insufficient evidence to indicate whether the fatigue properties of the spar boom from the crashed aircraft were significantly different from those of the other spar boom examined.—(21.2.1).

Utilisation des compteurs de Geiger-Müller a l'étude de variations de texture de laminage suivant la température de déformation. F. Provost. Pub. Sc. et Tech: No. 313. (1956).—(21.1 × 21.6.2).

Contribution a l'étude des phénomènes de durcissement dans l'alliage aluminium-cuivre a 4% *de cuivre. R. Graf. Pub. Sc. et Tech: No.* 315. (1956).—(21.2).

Investigation of the effect of impact damage on fatigue strength of jet-engine compressor rotor blades. A. Kaufman and A. J. Meyer. N.A.C.A. T.N. 3275. (*June* 1956).

Compressor rotor blades, which had suffered impact damage from a foreign object while being run in an axial-flow engine, were fatigue tested to determine the reduction in structural endurance. The most serious damage was nicks at the blade edges. The farther the damage was from the maximum-vibratory-stress section of the aerofoil and from the edges the less detrimental it was. The strength of the dented blades was restored by reworking them.—(21.2).

MATHEMATICS

A method for the numerical evaluation of an integral (occurring in the expression for the wave drag of slender bodies). T. Nonweiler. CoA Report No. 100.

Formulae and data are presented for the numerical integration of a double integral occurring in the expression for the wave drag of slender bodies. Comments are made on the accuracy and application of the method.—(22.1 × 1.2.0).

METEOROLOGY

Measurements of atmospheric turbulence over a wide range of wavelength for one meteorological condition. H. L. Crane and R. G. Chilton. N.A.C.A. T.N. 3702. (*June* 1956).

A power spectrum of gust vertical velocity over a wide range of wavelengths, 10 ft. to 60,000 ft., has been obtained by a simultaneous set of measurements in flight. The method used, which had the advantage of not involving aeroplane transfer functions, proved to be practicable. The data were obtained on film records and the power spectrum was calculated by digital methods.—(24).

POWER PLANTS

Turbojet cycle analysis: the effects of liquid injection at several points in the cycle. E. P. Cockshutt. N.A.E. L.R. 164. (*April* 1956).

The effects of injecting an evaporating liquid into the gas stream in a turbo-jet engine are calculated for liquid injection both upstream and downstream of the turbine. The response of the peak cycle temperature, engine fuel flow, tailpipe pressure, gross thrust and turbine pressure ratio, to the liquid injection are presented for a range of liquid latent heats and gas Mach numbers.—(27.1).

Selection of optimum configurations for heat exchanger with one dominating film resistance. E. R. G. Eckert and T. F. Irvine. N.A.C.A. T.N. 3713. (*June* 1956).

A study is presented for selecting an optimum configuration for a heat exchanger. Compact heat-exchanger configurations with one dominating film resistance are considered. Any one of the parameters (power, weight, volume, or frontal area) can be optimised against any one of the remaining three when the heat exchanger is arranged normal to the approaching primary fluid. When the heat exchanger is inclined at an angle to the upstream direction, any one of the parameters (power, weight, or volume) can be optimised against any one of the remaining two.—(27.1 × 1.9.1).

PROPELLERS

Flutter of thin propeller blades, including effects of Mach number, structural damping, and vibratory-stress measurements near the flutter boundaries. H. H. Hubbard, et al. N.A.C.A. T.N. 3707. (*June* 1956).

Experimental results are presented of an investigation on the flutter of thin propeller blades with three different plan forms. Flutter boundaries are presented for a highly twisted blade for which several modes of flutter were observed. Some effects of Mach number and structural damping on the flutter boundaries are described.—(29.1).

STRUCTURES

LOADS

See also HYDRODYNAMICS

The relationship between load spectra and fatigue life. B. Lundberg and S. Eggwertz. F.F.A. Report 67. (*March* 1956).

A study of available data on accelerations experienced by fighter aeroplanes indicates that the load spectrum for this category can be approximated by a straight line in a semi-log plot. For transport aeroplanes the same approximation has earlier been adopted. The important parameter of straight line spectra is the slope, the possible variation of which is analysed. Using the cumulative damage theory, the influence of this slope on the damage intensity curve and fatigue life of the element is investigated.—(33.1.1).

THEORY AND ANALYSIS

An approximate solution to the swept wing root constraint problem. D. Howe. CoA. Report 98.

An approximate solution is given for the problem associated with the root constraint in a swept wing. The structure considered is a uniform rectangular single cell box having closely spaced rigid ribs. Approximate allowance is made for the effect of boom area at the spar-skin joints. The stress distribution in the skin is represented by a polynomial in the chordwise ordinate, oblique co-ordinate notation being used. The final equations are derived by use of the theory of minimum strain energy. Consideration of the validity of the boom approximation shows it to be justified in two particular instances having relatively large boom area.—(33.2.3.2).

Double shear strength of B.S.L. 69 *snap head rivets in L.*72 *and L.*73 *aluminium alloy sheet. D. Howe. CoA Note* 50. (*July* 1956).

A limited series of tests has been carried out on single and double shear riveted joints using L.69 (D.T.D. 327) snap head rivets and L.72 (D.T.D. 610) and L.73 (D.T.D. 546) sheets. The specimens were similar to those used by the Royal Aircraft Establishment, the double shear specimens being essentially two single shear specimens placed back to back.—(33.2.4.13.1).

Bibliography and summaries of sandwich constructions (1939-1954). *J. Solvey. A.R.L. SM.*2 (*October* 1955).

This work of collection and classification of references on sandwich construction was initiated by the Royal Aeronautical Society's Structures Committee and a large part of it was completed during the period in which the author was seconded to the Society's Technical Staff. The bibliography consists of two parts, one covering theoretical and experimental work on strength, buckling, deformation and structural efficiency of sandwich panels, and the other covers the basic properties of materials, production and references of a more general nature. A précis is given of the material covered in each report and an author index is provided.—(33.2.4.6.0 × 33.2.4.9.0).

A method for the solution of instability problems. Analysis of pencils of singular Hermitian matrices. J. P. O. Silberstein. A.R.L. Report S.M. 233. (*September* 1955).

The spectral theory of non-singular pencils $A-B$ of Hermitian operators A, B is discussed for the case in which A and B may be singular. The general theory is used to develop a matrix iteration method suitable for the finite difference treatment of plate instability problems. The method is illustrated by an example.—(33.2.1).

Buckling of an infinite simply supported strip under combined longitudinal compression, transverse compression, bending and shear. W. H. Wittrick. A.R.L. Report S.M. 234 (*September* 1955).

The problem considered in this paper is that of the buckling of an infinite strip, simply supported on its edges, and subjected to the combined action of longitudinal and transverse compression, bending and shear. The solution is obtained by Galerkin's method which leads to a comparatively simple approximate relation between the four basic stress systems at buckling. Charts covering all possible combinations of the basic stress system are presented.—(33.2.4.5.0).

Measured strains in a swept tapered tube. Part I. J. E. Wheeler. A.R.L. Report S.M. 237. (*January* 1956).

The stresses found from tests on a swept tapered tube, representative of a two spar swept wing torsion box with ribs in line-of-flight, are compared at a section far removed from the root with those given by a theory due to Wittrick. Comparison is also made with those stresses predicted by the simple theories of bending and torsion.—(33.2.1.0 × 33.2.3.2).

On the determination of the lateral stability of beams. L. H. Mitchell. A.R.L. Technical Memo. S.M. 54. (*March* 1956).

An energy equation for determining the lateral stability load of a beam is derived for the case in which the lateral moment of inertia is not small. The end conditions of the beam are either simply-supported or built-in.—(33.2.4.1.6).

*Die Stabilität geschichteter Streifen. A. van der Neut. N.L.L. Bericht S.*284. (1943).—(33.2.4.6).

*Die Stabilität geschichteter Platten. A. van der Neut. N.L.L. Bericht S.*286. (1943).—(33.2.4.6).

*The elastic overall instability of sandwich plates with simply supported edges. F. J. Plantema and A. C. De Kock. N.L.L Report S.*346.

The energy method for calculating buckling loads of sandwich plates, developed by the first author, is applied to a simply-supported infinitely long plate subjected to shear. The results are compared with those obtained in previous papers and are presented in a number of simple graphs. Non-dimensional interaction curves for combined compression or tension and shear are given and, finally, all of the results obtained by means of the energy method are recapitulated.—(33.2.4.6.4).

Strength of 75 S-T integral compression skins in box-beams under pure bending. S. Eggwertz. FFA. Report 64 (*Stockholm* 1956).

Eight one-cell and three two-cell box-beams with unstiffened 75 S-T aluminium alloy compression skins integrally connected to the webs, have been tested under pure bending, the strain being measured at a large number of points, particularly on the compression side. The main interest has been concerned with the stress distribution at failure and the maximum average stress in the compression skin has been related to the buckling stress and the maximum corner stress, which is approximately equal to the yield strength of the material. After comparing the test results with published theoretical and experimental investigations on plate sections under pure compression, an empirical procedure is advanced for calculating the maximum bending moment that can be applied to box-beams with two or more webs. This procedure is thought to be applicable to extruded aluminium and magnesium alloys and also, roughly, to rolled plates of the same materials in riveted structures.—(33.2.4.6.1).

Comparison of theoretical and experimental results for 24 *S-T and* 75 *S-T aluminium alloy columns buckling in the elastic and inelastic ranges. B. Braathen and B. R. Noton. F.F.A. Report* 66. (1956).

An investigation of the elastic and inelastic buckling of pin-ended and flat-ended 24 S-T and 75 S-T aluminium alloy columns of rectangular cross section has been carried out. One hundred and fifty specimens in both extruded and rolled materials were tested. To facilitate a study of the extended Southwell method for predicting buckling loads, strain gauge readings have been taken on some of the pin-ended columns in 24 S-T aluminium alloy. The theoretical ultimate loads were calculated using the tangent-modulus theory, the reduced-modulus theory and the extended Southwell method, and curves of comparison have been prepared from these values.—(33.2.4.2.1).

On the buckling of bars and plates in the plastic range. Part II. J. P. Benthem. N.A.C.A. T.N. 1392 (*March* 1956).

A review is made of existing literature concerning comparison with experiment of various theoretical formulae for buckling of plates in the plastic region. The significance and relative merits of various theories are discussed.—(33.2.4.5.6 × 33.2.2).

Some effects of joint conductivity on the temperatures and thermal stresses in aerodynamically heated skin-stiffener combinations. G. E. Griffith and G. H. Miltonberger. N.A.C.A. T.N. 3699. (*June* 1956).

Temperatures and thermal stresses in aerodynamically heated skin-stiffener combinations were calculated with the aid of an electronic differential analyser. Variations were made in an aerodynamic heat-transfer parameter, a joint conductivity parameter, and the ratio of skin width to skin thickness.—(33.2.4.6.9).

TESTING

Investigations into a photoelastic method for direct measurement of surface strains in metal components. J. R. Linge. CoA Report 97. (*February* 1956).

The technique investigated consists of the examination of surface strains in a metal component with optically sensitive material bonded to the component and the analyses of the photoelastic pattern produced under load by means of polarised light reflected from the surface of the metal. Results of the measurement of both elastic and plastic stress concentrations at holes in plates subjected to uniform tension are presented, together with a qualitative analysis of the effect on stress distribution of the variation of the pin to hole clearance in lugs.—(33.3.2).

THERMODYNAMICS

*A rapid analytical method for calculating the early transient temperature in a composite slab. W. F. Campbell. N.R.C. Report No. MT-*32. (*April* 1956).

The one-dimensional heat conduction problem in a slab made up of several layers, each with uniform thermal properties, may be solved analytically for a great variety of boundary conditions, for short times, by a method analogous to electric transmission line theory. Graphs of functions derived from the error function are included to aid numerical calculation. The method is also applicable to some steady state harmonic heat conduction problems.—(34.4).

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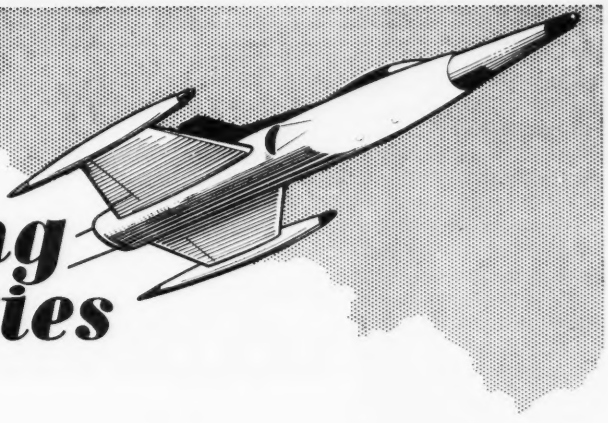

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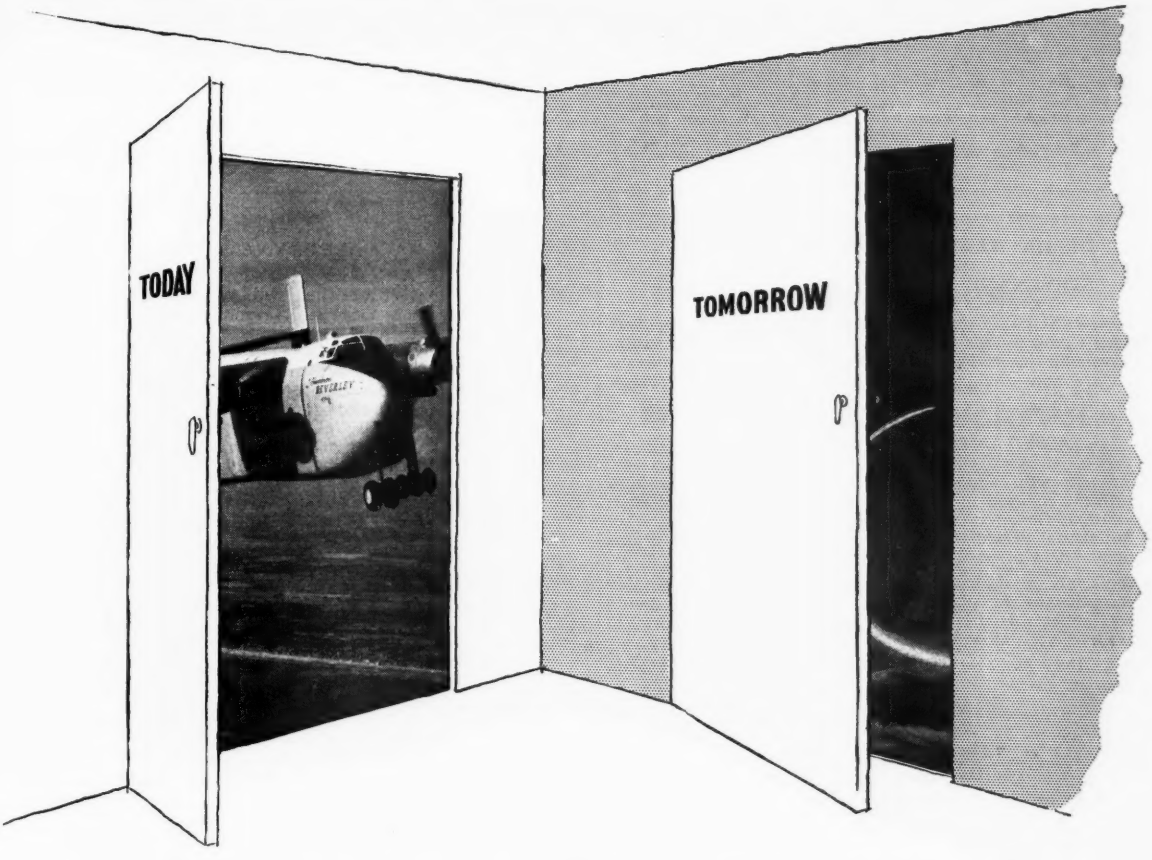

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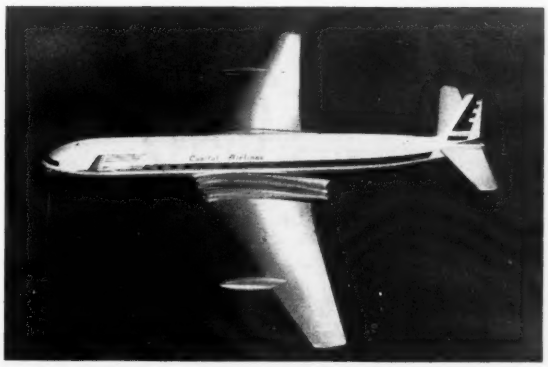

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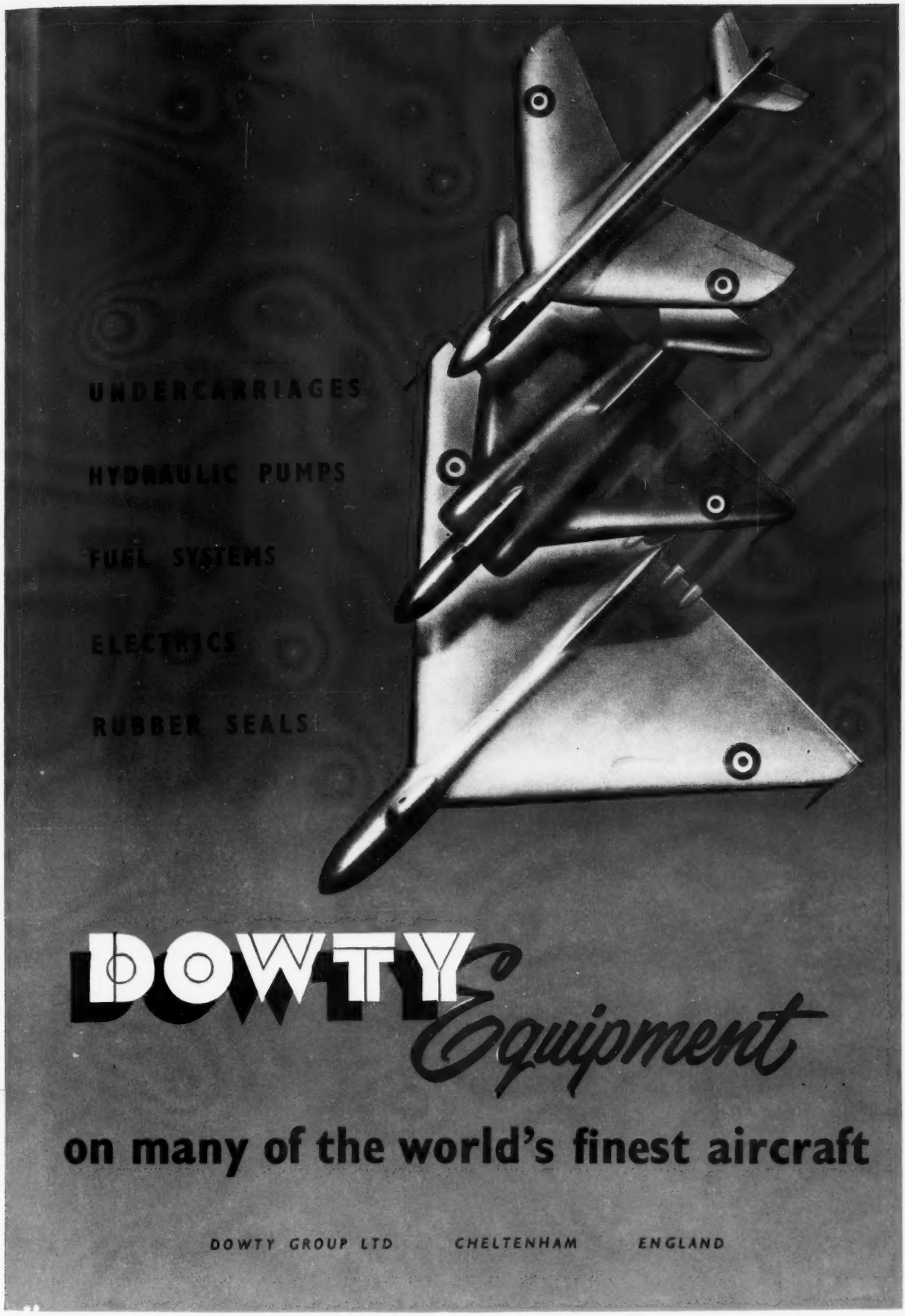

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